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ALTITUDE DEVELOPMENT AND FLIGHT SUPPORT TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TEST J4-1901-12)

C. H. Kunz

ARO, Inc.

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LARGE ROCKET FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

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FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) (I-E-J), under System 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract F40600-69-C-0001. Program direction was provided by NASA/MSFC; engineering liaison was provided by North American Rockwell Corporation, Rocketdyne Division, manufacturer of the J-2 rocket engine and McDonnell Douglas Corporation, Missile and Space Systems Division, manufacturer of the S-IVB stage. The testing reported herein was conducted on October 8, 1968, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1901. The manuscript was submitted for publication on November 14, 1968.

This technical report has been reviewed and is approved.

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ABSTRACT

Six firings of the Rocketdyne J-2 rocket engine (S/N J-2036-1) were conducted during test period J4-1901-12 on October 8, 1968, in Test Cell J-4 of the Large Rocket Facility. This testing was in support of the J-2 engine application on the Saturn IB vehicle. The primary objective of this test period was to evaluate engine start transients with the engine orificed for an uprated thrust level of 240,000 lb_f at a 5.5 mixture ratio. The engine was orificed for performance significantly in excess of the target level, and in fact for a value which could not be attained without exceeding safe operation limits. However, engine start transients were satisfactory with the propellant utilization valve in the open position. The total accumulated firing duration for the six firings was 63.9 sec.

CONTENTS

APPENDIXES

NOMENCLATURE

A	Area, in.^{2}
ASI	Augmented spark igniter
ES	Engine start, designated as the time that helium control and ignition phase solenoids are energized
GG	Gas generator
MOV	Main oxidizer valve

STDV	Start tank discharge valve
t_0	Defined as the time at which the opening signal is applied to the start tank discharge valve solenoid
VSC	Vibration safety counts, defined as the time at which engine vibration was in excess of 150 g rms in a 960- to 6000-Hz frequency range

SUBSCRIPTS

f	Force
m	Mass
t	Throat

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2 rocket engine using an S-IVB battleship stage has been in progress since July, 1966, at AEDC in support of the J-2 engine application on the Saturn IB and Saturn V launch vehicles for the NASA Apollo Program. The six firings reported herein were conducted during test period J4-1901-12 on October 8, 1968, in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF).

The main objective of these firings was to evaluate engine start transients at simulated altitude conditions with the engine orificed to produce an uprated thrust level of 240,000 lb_f at a mixture ratio of 5.5 (rated thrust for this engine is 230,000 lb_f at a mixture ratio of 5.5). The firings were conducted at pressure altitudes ranging from 86,000 to 100,000 ft (geometric pressure altitude, Z, Ref. 1) at engine start. Engine components were conditioned to expected S-IB temperatures at engine start. Data collected to accomplish the test objectives are presented herein. The results of the previous test period are presented in Ref. 2.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2 rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Rockwell Corporation. The engine uses liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 230,000 lb_f at an oxidizer-to-fuel mixture ratio of 5.5. The engine, as received at AEDC, was designated S/N J-2036-1, signifying that it is a rebuilt engine. In rebuilding, modifications were performed to configure the engine identically with engine S/N J-2072 and subsequent engines. An S-IVB battleship stage was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for this test period are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed since the previous test period are presented in Tables III and IV, respectively.

2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 5, Ref. 3) features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber (8.0 in. long from the injector mounting to the throat inlet) with a characteristic length (L*) of 24.6 in., a 170.4-in.^{2} throat area, and a divergent nozzle with an expansion ratio of 27.1. Thrust chamber length (from the injector flange to the nozzle exit) is 107 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector.

2. Thrust Chamber Injector - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 25.0 and 16.0 in.^{2}, respectively. The porous material, forming the injector face, allows approximately 3.5 percent of total fuel flow to transpiration cool the face of the injector.

3. Augmented Spark Igniter - The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.

4. Fuel Turbopump - The turbopump is composed of a two-stage turbine-stator assembly, an inducer, and a seven-stage axial-flow pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 38,215 ft (1248 psia) of liquid hydrogen at a flow rate of 8585 gpm for a rotor speed of 27,265 rpm.

5. Oxidizer Turbopump - The turbopump is composed of a two-stage turbine-stator assembly and a single-stage centrifugal pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 2170 ft (1107 psia) of liquid oxygen at a flow rate of 2965 gpm for a rotor speed of 8688 rpm.

6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated

control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel lead to the gas generator combustion chamber. The high energy gases produced by the gas generator are directed to the fuel turbine and then to the oxidizer turbine (through the turbine crossover duct) before being exhausted into the thrust chamber at an area ratio (A/A_t) of approximately 11.

7. Propellant Utilization Valve - The motor-driven propellant utilization valve is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.

8. Propellant Bleed Valves - The pneumatically operated fuel and oxidizer bleed valves provide pressure relief for the boiloff of propellants trapped between the battleship stage prevalves and main propellant valves at engine shutdown.

9. Integral Hydrogen Start Tank and Helium Tank - The integral tanks consist of a 7258-in.^{3} sphere for hydrogen with a 1000-in.^{3} sphere for helium located within it. Pressurized gaseous hydrogen in the start tank provides the initial energy source for spinning the propellant turbopumps during engine start. The helium tank provides a helium pressure supply to the engine pneumatic control system.

10. Oxidizer Turbine Bypass Valve - The pneumatically actuated oxidizer turbine bypass valve provides control of the fuel turbine exhaust gases directed to the oxidizer turbine in order to control the oxidizer-to-fuel turbine spinup relationship. The fuel turbine exhaust gases which bypass the oxidizer turbine are discharged into the thrust chamber.

11. Main Oxidizer Valve - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high pressure duct between the turbopump and the main injector. The first-stage actuator positions the main oxidizer valve at the 14-deg position to obtain initial thrust chamber ignition; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to main-stage operation.

12. Main Fuel Valve - The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high pressure duct between the turbopump and the fuel manifold.

13. Pneumatic Control Package - The pneumatic control package controls all pneumatically operated engine valves and purges.

14. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation.

15. Primary and Auxiliary Flight Instrumentation Packages - The instrumentation packages contain sensors required to monitor critical engine parameters. The packages provide environmental control for the sensors.

2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 46,000 lb of liquid hydrogen and 199,000 lb of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant prevalves, in the low pressure ducts (external to the tanks) interfacing the stage and the engine, retain propellant in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Propellant recirculation pumps in both fuel and oxidizer tanks are utilized to circulate propellants through the low pressure ducts and turbopumps before engine start to stabilize hardware temperatures near normal operating levels and to prevent propellant temperature stratification. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen for fuel tank pressurization during S-IVB flight was routed to the facility venting system.

2.2 TEST CELL

Test Cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100,000 ft. The basic cell construction provides a 1.5-million-lbf-thrust capacity. The cell consists of four major components (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant

water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), and liquid oxygen and gaseous helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

The battleship stage and the J-2 engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

An engine component conditioning system was provided for temperature conditioning engine components. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning. Engine components requiring temperature conditioning were the thrust chamber, crossover duct, and main oxidizer valve second-stage actuator. Helium was routed internally through the crossover duct and tubular-walled thrust chamber. Main oxidizer valve conditioning was achieved by opening the prevalves and permitting propellants into the engine.

2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of (1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage-type pressure transducers and a capacitance-type Photocon® transducer. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates of the engine were measured by turbine-type flowmeters which are an integral part of the engine. The propellant recirculation flow rates were also monitored with turbine-type flowmeters. Vibrations were measured by accelerometers mounted on the oxidizer injector dome and on the turbopumps. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers and resistance temperature transducer units; (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flowmeters; and (4) frequency-voltage substitution for accelerometers and Photocon unit.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system (Microsadic®) scanning each parameter at 40 samples per second and recording on magnetic tape; (2) single-input, continuous-recording FM systems recording on magnetic tape; (3) photographically recording galvanometer oscillographs; (4) direct-inking, null-balance potentiometer-type X-Y plotters and strip charts; and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.

2.4 CONTROLS

Control of the J-2 engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for a normal start and shutdown is presented in Figs. 7a and b. Two control logics for sequencing the stage prevalves and recirculation systems with engine start for simulating engine flight start sequences are presented in Figs. 7c and d.

SECTION III
PROCEDURE

Preoperational procedures were begun several hours before the test period. All consumable storage systems were replenished, and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer dome, gas generator oxidizer injector, and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period, except for the engine firing. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Temperature conditioning of the various engine components was accomplished as required, using the facility-supplied engine component conditioning system. Engine components which required temperature conditioning

were the thrust chamber, the crossover duct, and main oxidizer valve second-stage actuator. Table V presents the engine purges and thermal conditioning operations during the terminal countdown and immediately following the engine firing.

SECTION IV
RESULTS AND DISCUSSION

4.1 TEST SUMMARY

4.1.1 General

Six firings of the Rocketdyne J-2 rocket engine (S/N J-2036-1) were conducted during test period J4-1901-12 on October 8, 1968. The principle objective of these firings was to evaluate engine start transients at simulated altitude conditions with the engine orificed to an uprated thrust level of 240,000-lb_f thrust, at an oxidizer-to-fuel mixture ratio of 5.5. The engine was operated 63.9 sec during this test period. This resulted in a total accumulated operating time at AEDC on engine S/N J-2036-1 of 828.8 sec.

Test requirements and specific test results are summarized in Table VI. Start and shutdown transients operating times for selected engine valves are shown in Table VII. Calculated engine steady-state performance data are shown in Table VIII. Figure 8 shows engine start conditions for the pump inlets, start tank, and helium tank for all firings. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firings, engine start and shutdown transients, and fuel pump start transient performance are presented in Figs. 9 through 32. The data presented will be those recorded on the digital data acquisition system, except as noted. Specific test objectives and a brief summary of results obtained for each firing are presented in the following sections.

4.1.2 Firing J4-1901-12A

4.1.2.1 Objectives

The objective was to evaluate the engine start transient with the propellant utilization valve in the open position and with the engine orificed for uprated performance of 240,000-lb_f thrust at an engine mixture ratio of 5.5 (propellant utilization valve in the closed position).

4.1.2.2 Results

The firing was prematurely terminated at t_0 + 12.522 sec by the engine safety cutoff system because of fuel turbine speed exceeding the safety limit of 29,000 ± 250 rpm. The engine was started with the propellant utilization valve in the open position, and the safety cutoff occurred 0.805 sec after this valve was moved to the closed position. Analysis of test data indicated the engine had actually been orificed such that thrust was significantly in excess of 240,000 lb_f with the propellant utilization valve in the closed position. Thrust at engine cutoff was approximately 253,000 lb_f and increasing; mixture ratio reached a maximum value of 5.28 (t_0 + 11.8 sec) and was 5.14 and decreasing at engine cutoff (Fig. 33). This incorrect engine orificing resulted in the fuel turbine overspeed. The engine start transient with the open propellant utilization valve position and with this thrust configuration appeared satisfactory. Engine normalized thrust and mixture ratio before and after the propellant utilization valve excursion are presented in Fig. 34.

4.1.3 Firing J4-1901-12B

4.1.3.1 Objectives

The objectives were to evaluate the engine start transient with the propellant utilization valve in the open position and engine orificed for uprated performance and make a propellant utilization valve excursion at t_0 + 10 sec for determination of engine performance with this valve in the null position.

4.1.3.2 Results

The firing was successfully accomplished, and the test objectives were met. The engine start transient appeared satisfactory, and the propellant utilization valve excursion was successfully accomplished. Engine steady-state normalized performance (Table VIII) indicated mixture ratio (4.8) was 0.2 mixture ratio units low, and thrust (223,000 lb_f) was 26,000 lb_f above rated performance at the 4.8 mixture ratio.

4.1.4 Firing J4-1901-12C

4.1.4.1 Objectives

The objectives were to evaluate the engine start transient with the propellant utilization valve in the open position, with the engine orificed for the uprated thrust level and with maximum starting energy.

4.1.4.2 Results

The firing was successfully accomplished; however, maximum starting energy was not obtained because of the reduction in effective starting energy by a propellant leak through either the gas generator control valve or the fuel turbine seals which chilled fuel turbine components below the target limits. The engine start transient under these conditions appeared satisfactory. Post-firing 12C purging of the gas generator and turbine components with ambient helium apparently eliminated this leak.

4.1.5 Firing J4-1901-12D

4.1.5.1 Objectives

The objectives were to evaluate fuel pump high level stall margin with the propellant utilization valve in the open position, with the engine orificed for the uprated thrust level and with minimum starting energy.

4.1.5.2 Results

The firing was successfully accomplished, and the test objectives was met. The minimum high level stall margin was conservative (700 gpm).

4.1.6 Firing J4-1901-12E

4.1.6.1 Objectives

The objectives were to evaluate fuel pump stall margin during start tank discharge with the propellant utilization valve in the null position, with the engine orificed for the uprated thrust level and with other starting conditions the same as for firing 12A.

4.1.6.2 Results

The firing was successfully accomplished, and the test objectives were met. The fuel pump stall margin during start tank discharge was essentially the same as that experienced on firing 12A (1800 gpm). Comparison of start transient data with firing 12A indicates excessive gas generator temperature transients may result during the start transient with the propellant utilization valve in the null position and with the engine orificed for the uprated thrust level.

4.1.7 Firing J4-1901-12F

4.1.7.1 Objectives

The objective was to evaluate the engine start transient with the propellant utilization valve in the open position, with the engine orificed for the uprated thrust level and with maximum starting energy. This was to repeat target conditions for firing 12C which were not met.

4.1.7.2 Results

The firing was successfully accomplished, and the test objectives were met. The engine start transient appeared satisfactory.

4.2 ENGINE STEADY-STATE PERFORMANCE

Engine steady-state performance data are presented in Table VIII for a 1-sec data average between 29 and 30 sec after t_0 (propellant utilization valve in the null position) for firing 12B. These data were computed using the Rocketdyne PAST 640, modification zero, performance computer program. Engine test measurements required by the program and the program computations for the normalized data are presented in Appendix IV.

The engine was reorificed before this test period to attain the uprated thrust level of 240,000 lb_f (10,000 lb_f above rated thrust at a mixture ratio of 5.5). However, during firing 12A, it was found that 0.805 sec after the propellant utilization valve was moved from the open to the closed position at approximately t_0 + 11 sec, to attain the desired thrust, safe operating limits were exceeded, and the firing was prematurely terminated by the engine safety cutoff system. Analysis of test data indicated the engine had been orificed significantly in excess of 240,000-lb_f thrust.

Thrust and mixture ratio transients during the propellant utilization valve excursion on firing 12A are shown in Fig. 33. This figure shows that thrust at engine cutoff was 253,000 lb_f and increasing; mixture ratio reached a maximum of 5.28 (t_0 + 11.8 sec) and was 5.14 and decreasing at engine cutoff. Performance data are not presented in Table VIII since steady-state operation was not attained with the propellant utilization valve in the closed position. However, normalized thrust and mixture ratio were 249,200 lb_f and 5.25, respectively, at engine cutoff (Fig. 34). Nominal mixture ratio with the closed propellant utilization valve position is 5.5.

During firing 12B, the propellant utilization valve was moved from the open to the null position at approximately t_0 + 11 sec, and main-stage operation was successfully accomplished at this operating point. Normalized performance data from this firing are compared to rated thrust and mixture ratio for this engine orificed for 230,000-lb_f thrust, as shown in Fig. 34. With the propellant utilization valve in the null position (nominal 5.0 mixture ratio), Fig. 34 shows that the mixture ratio was 4.8 and thrust (223,000-lb_f) was 26,000 lb_f above rated thrust at this mixture ratio. This figure also shows the same trend of low mixture ratio and high thrust with the propellant utilization valve in the open position at t_0 + 10 sec on firings 12A and 12B.

4.3 EFFECT OF PROPELLANT UTILIZATION VALVE POSITION ON ENGINE START TRANSIENTS

Conditions at engine start for firing 12A were repeated during firing 12E, except for the propellant utilization valve position. Firing 12E was conducted with this valve in the null position, whereas 12A was conducted utilizing the open position. Selected engine parameters are compared during the start transient for these firings in Fig. 35. This figure shows that the null propellant utilization valve position resulted in a faster engine buildup rate. Main chamber pressure attained 100 psi at t_0 + 0.935 sec with this valve in the null position (25 msec faster than with the open position), and main-stage pressure "OK" event occurred at t_0 + 1.425 sec (185 msec faster than with the open position).

The gas generator outlet temperature reached a maximum value of 2110°F with the propellant utilization valve in the null position (480°F higher than with the open position) and was in excess of 1550°F at engine cutoff (440°F higher than at the same time with the open position on firing 12A). These data indicate excessive gas generator start transient temperature may result with the propellant utilization valve in the null position and with the engine orificed for the uprated thrust level.

Fuel pump start transient performance for firings 12A and 12E is compared in Fig. 36. This figure shows that propellant utilization valve position did not have a significant effect on fuel pump stall margin during start tank discharge. This stall margin was conservative on both firings (1800 gpm).

SECTION V
SUMMARY OF RESULTS

The results of the six firings conducted during test period J4-1901-12 on October 8, 1968, with the engine orificed for the uprated thrust level are summarized as follows:

1. Engine main-stage operation was satisfactory with the propellant utilization valve in the open and null position; however, safe operating limits were exceeded when an excursion to the closed position was made, indicating that engine orificing was such that thrust was significantly in excess of the desired operating level of 240,000 lb_f.
2. Engine start transients were satisfactory with the propellant utilization valve in the open position; however, data indicate excessive gas generator transient temperature may result with this valve in the null position.
3. Propellant utilization valve position did not have a significant effect on fuel pump stall margin during start tank discharge. The fuel pump high level stall margin was conservative with minimum starting energy.

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APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION
IV. METHOD OF CALCULATIONS (PERFORMANCE PROGRAM)

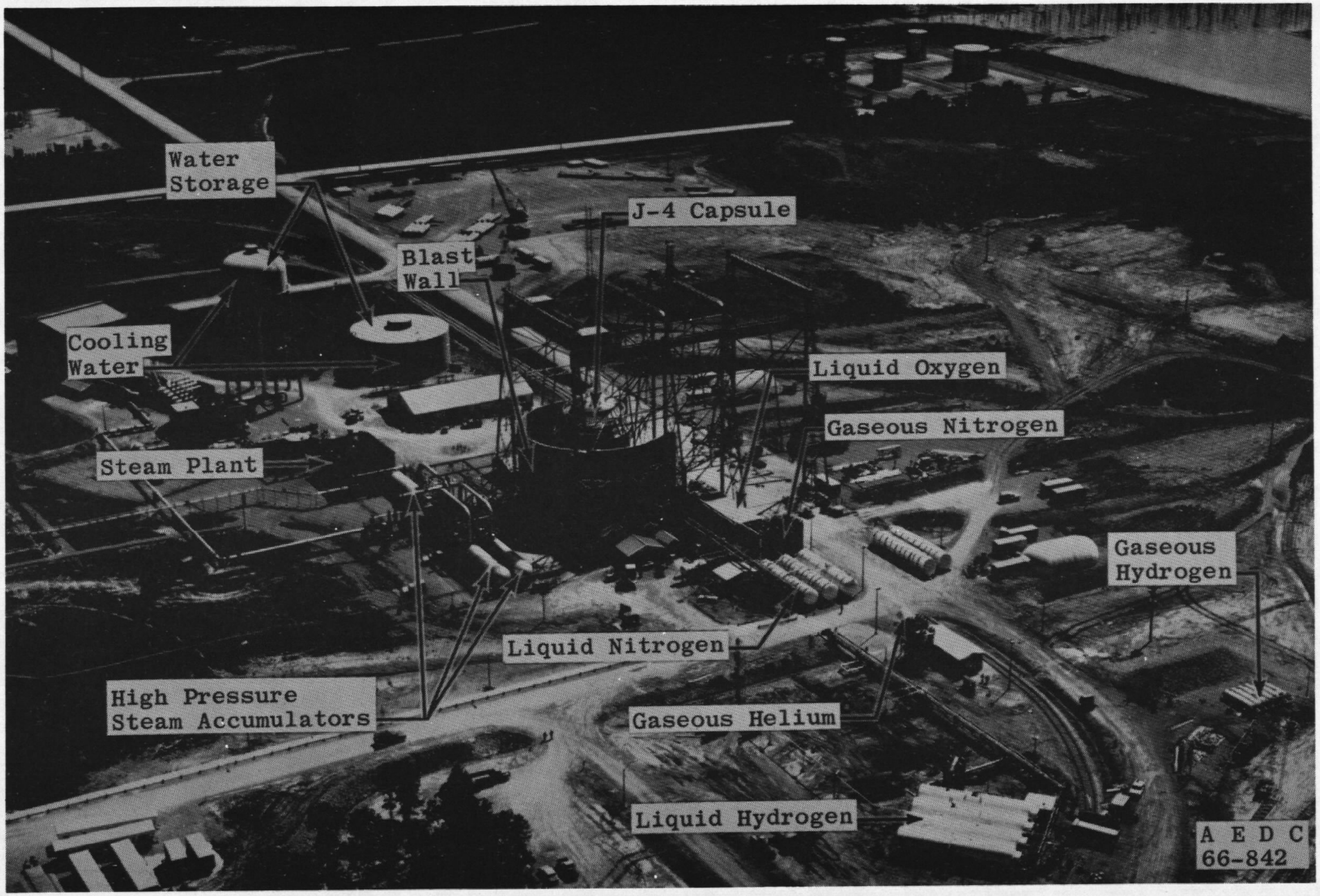


Fig. 1 Test Cell J-4 Complex

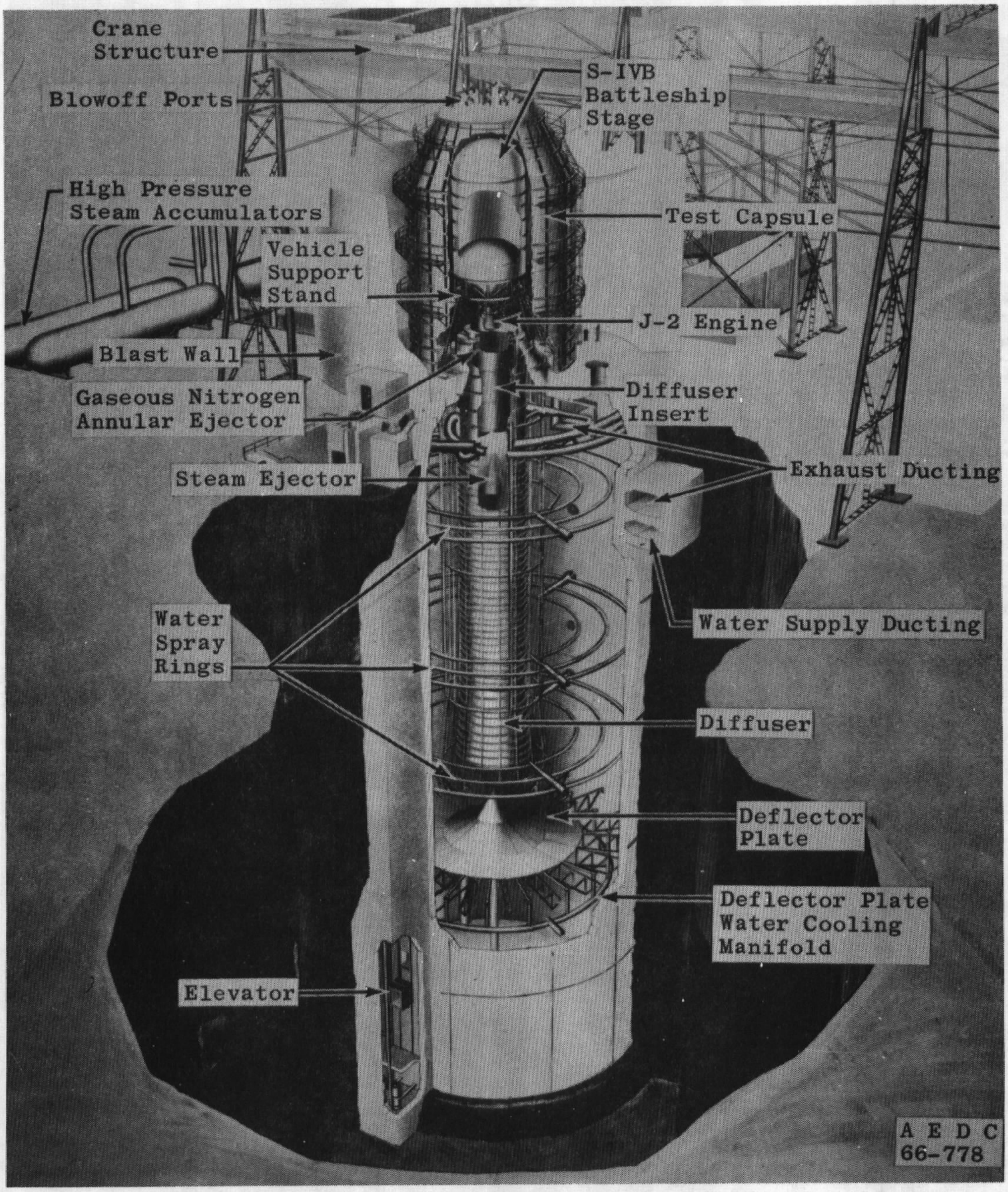


Fig. 2 Test Cell J-4, Artist's Conception

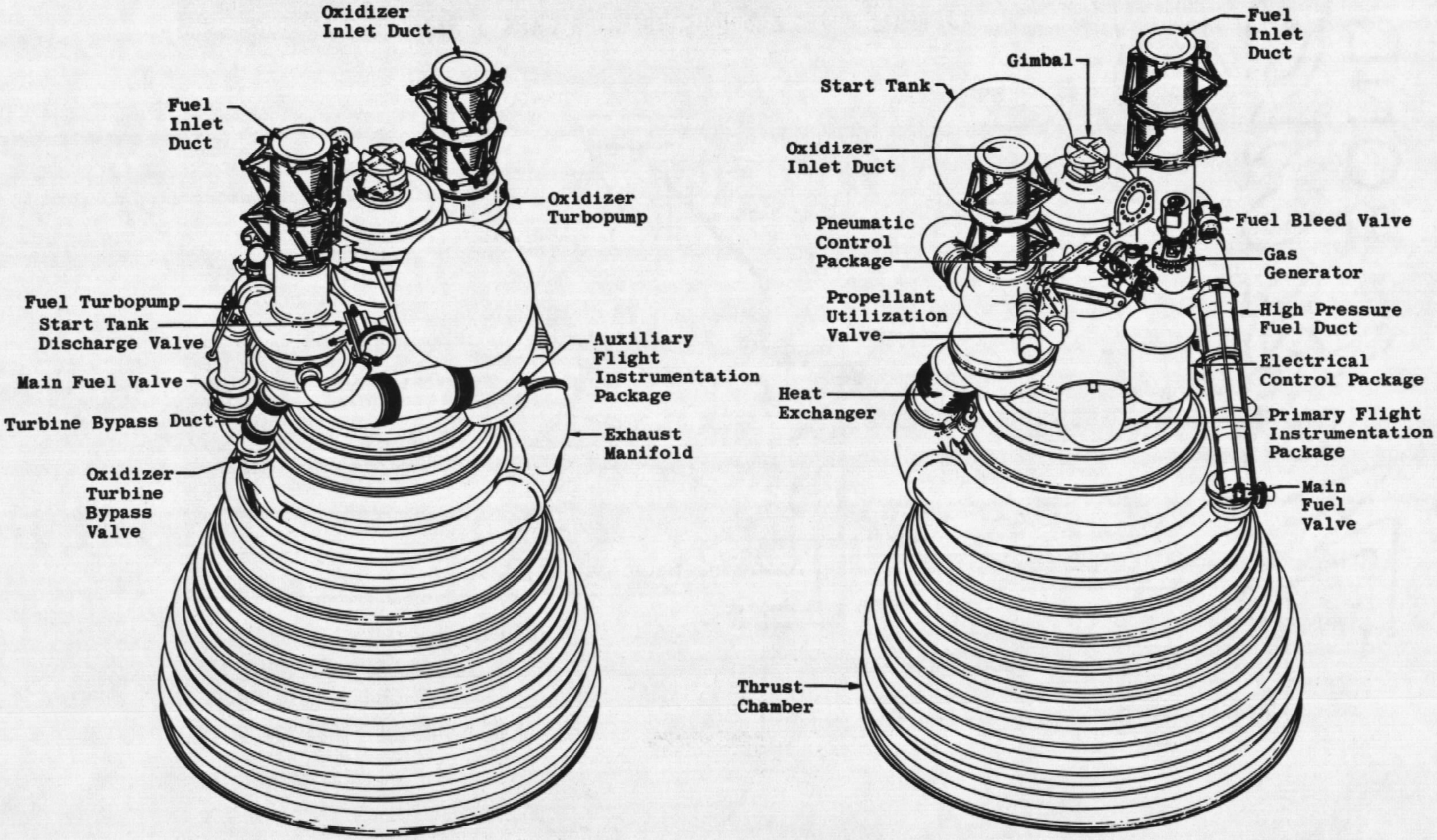


Fig. 3 Engine Details

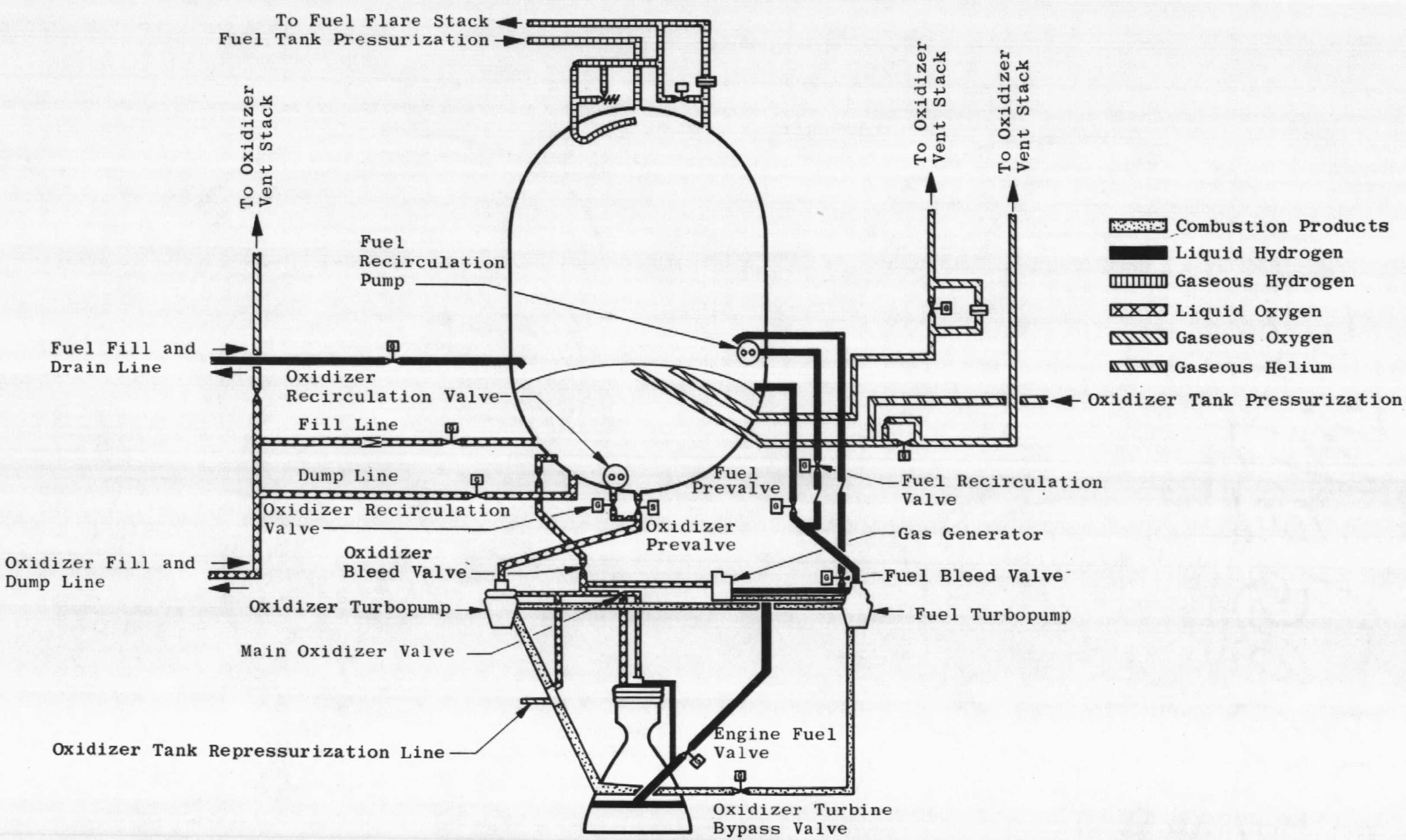


Fig. 4 S-IVB Battleship Stage/J-2 Engine Schematic

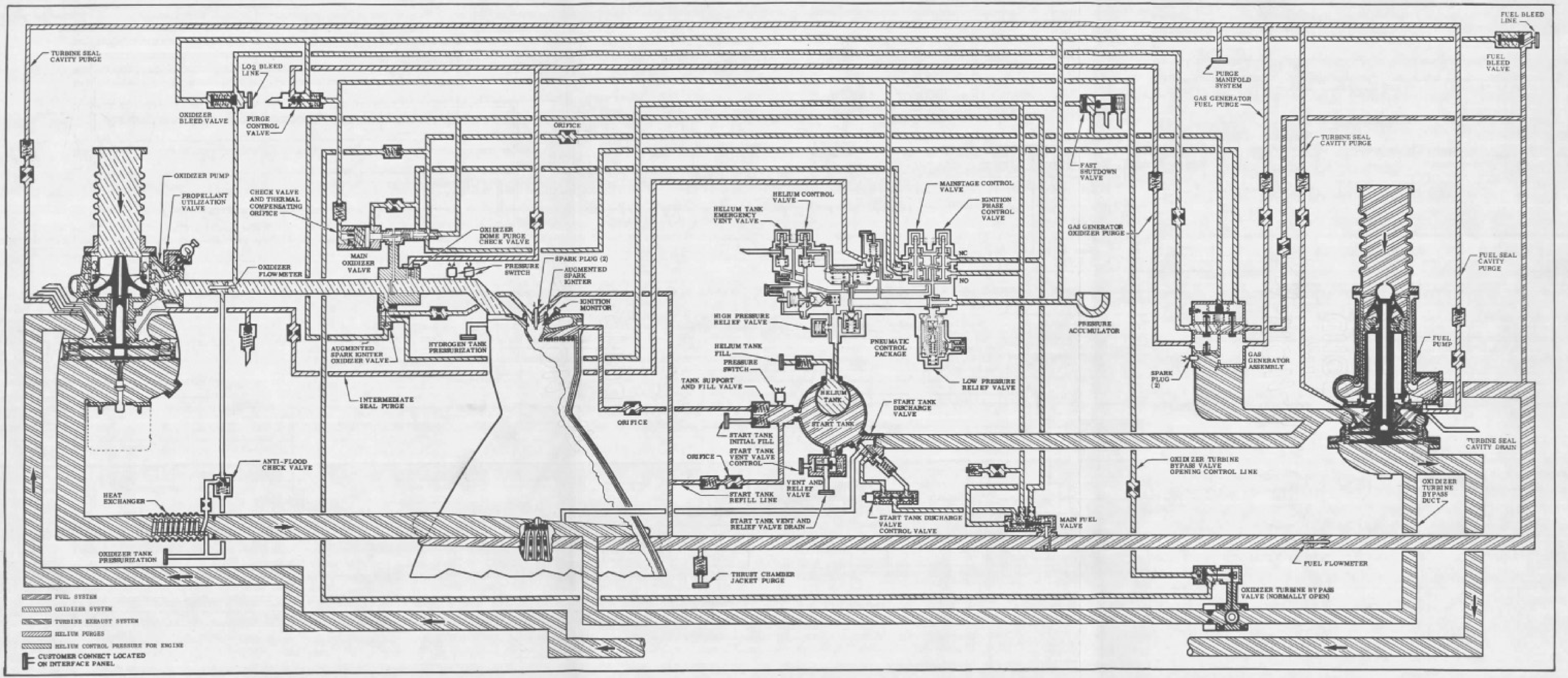


Fig. 15 Mechanical Schematic of the J-2 Engine

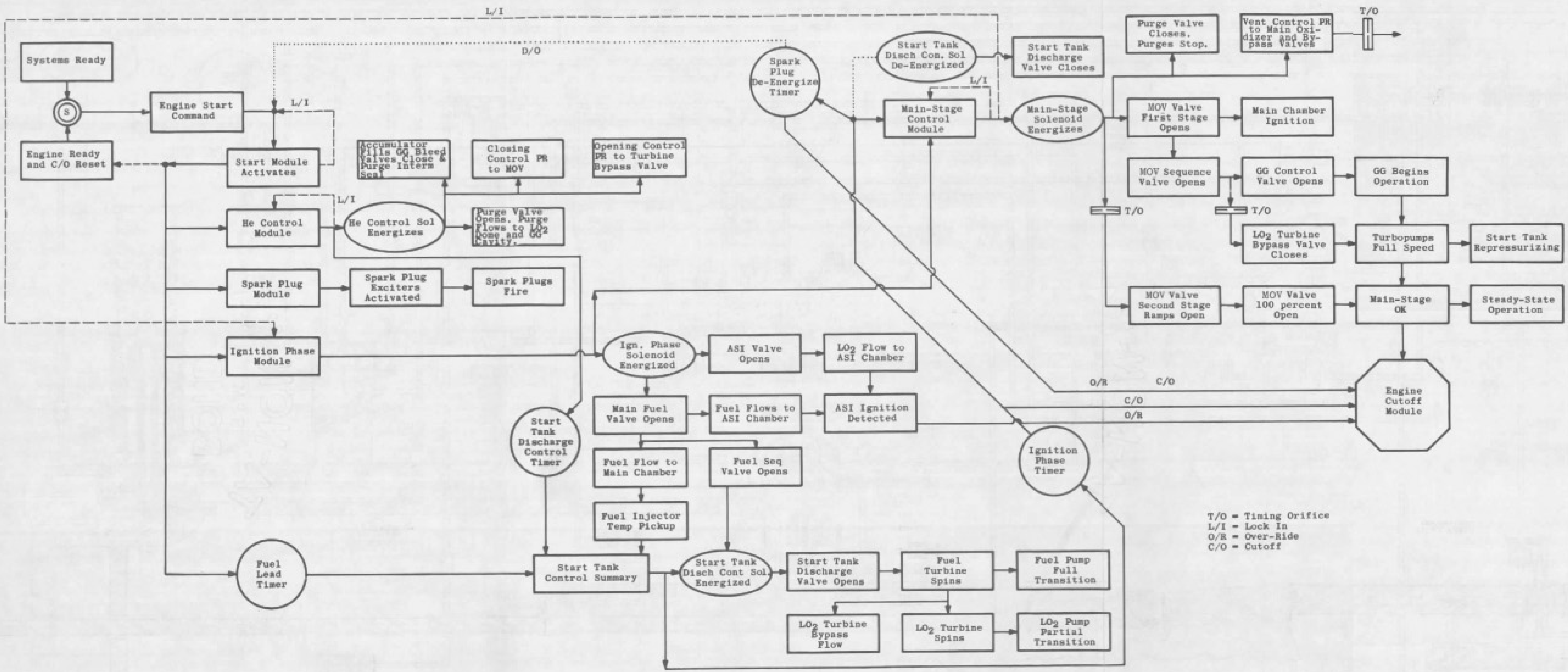
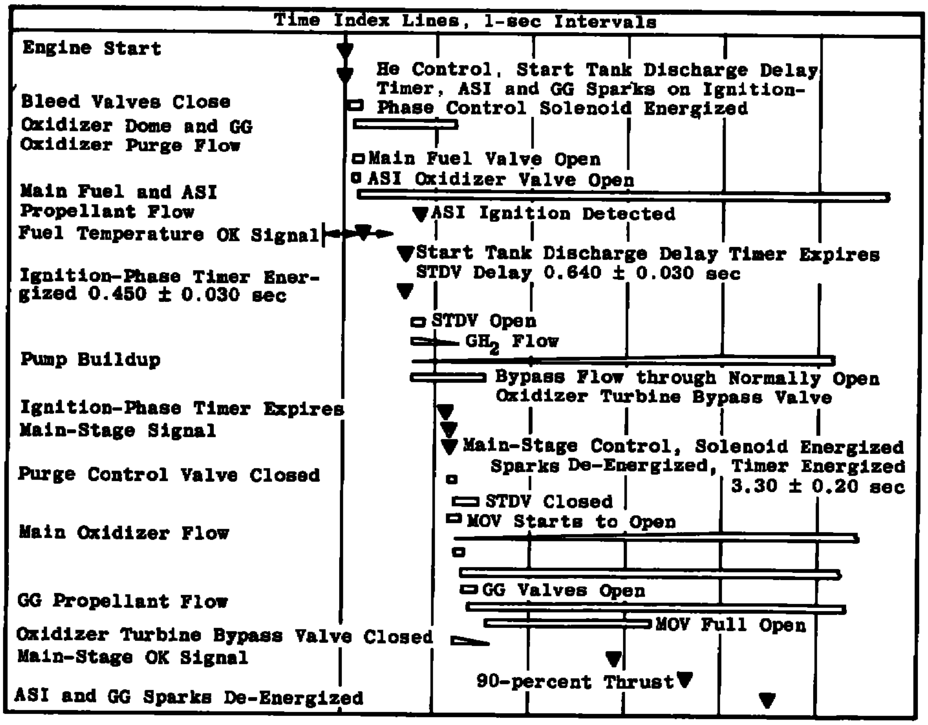
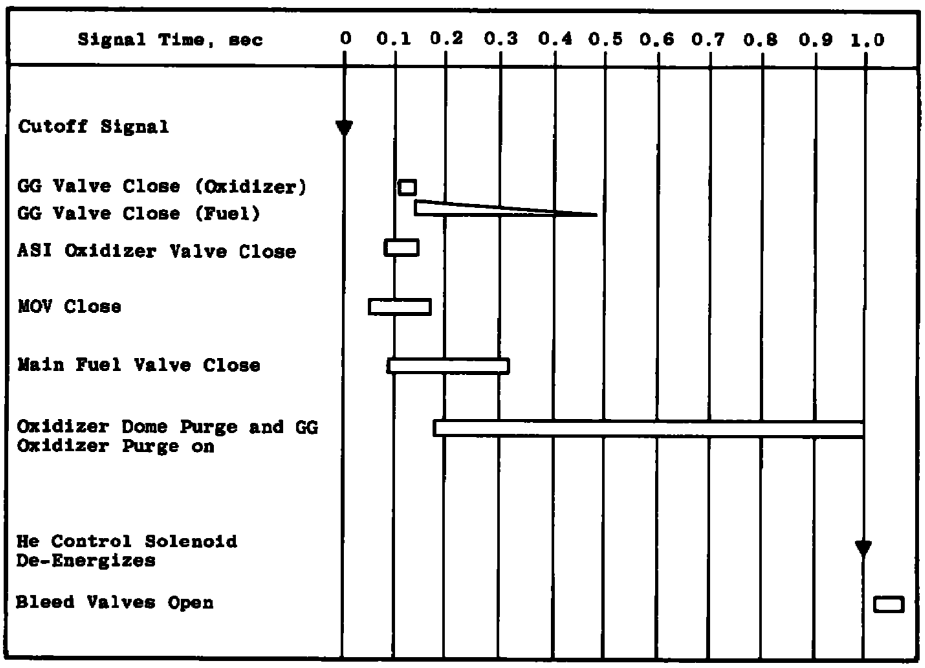


Fig. 16 Logic Schematic of the J-2 Engine Start

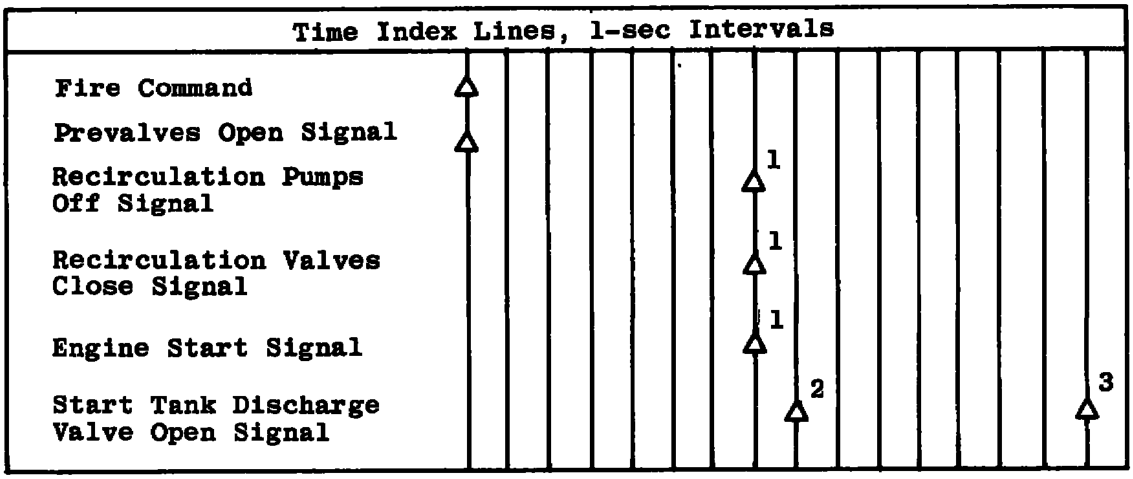


a. Start Sequence



b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence

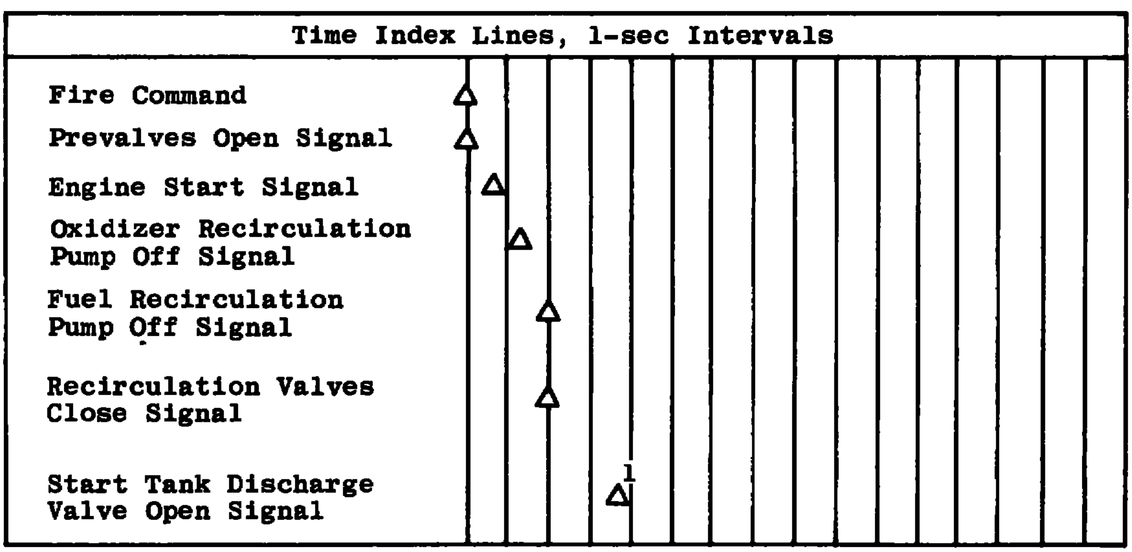


[1]Nominal Occurrence Time (Function of Prevalves Opening Time)

[2]One-sec Fuel Lead (S-II/S-V and S-IVB/S-IB)

[3]Eight-sec Fuel Lead (S-IVB/S-V and S-IB Orbital Restart)

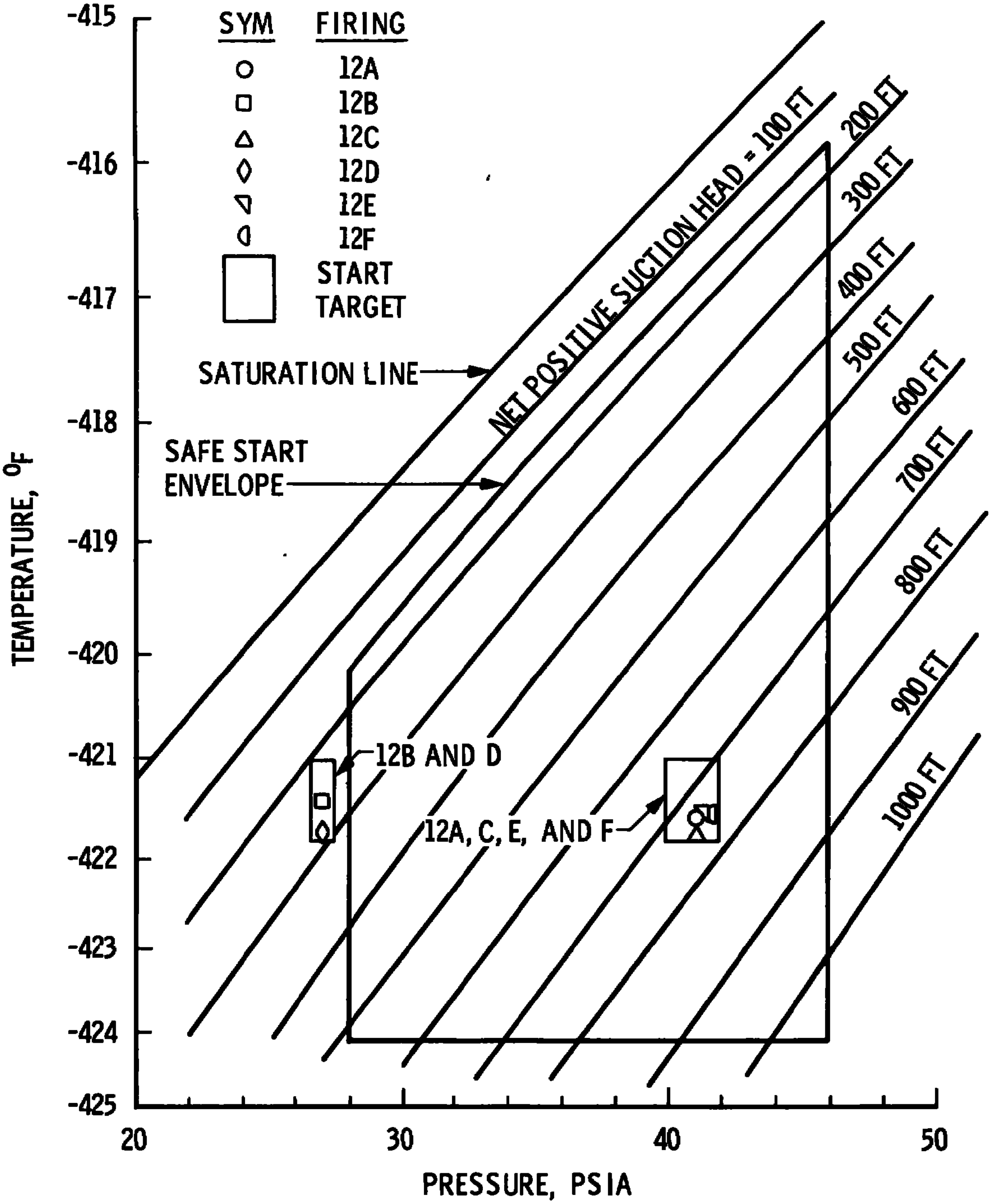
c. Normal Logic Start Sequence



[1]Three-sec Fuel Lead (S-IVB/S-V First Burn)

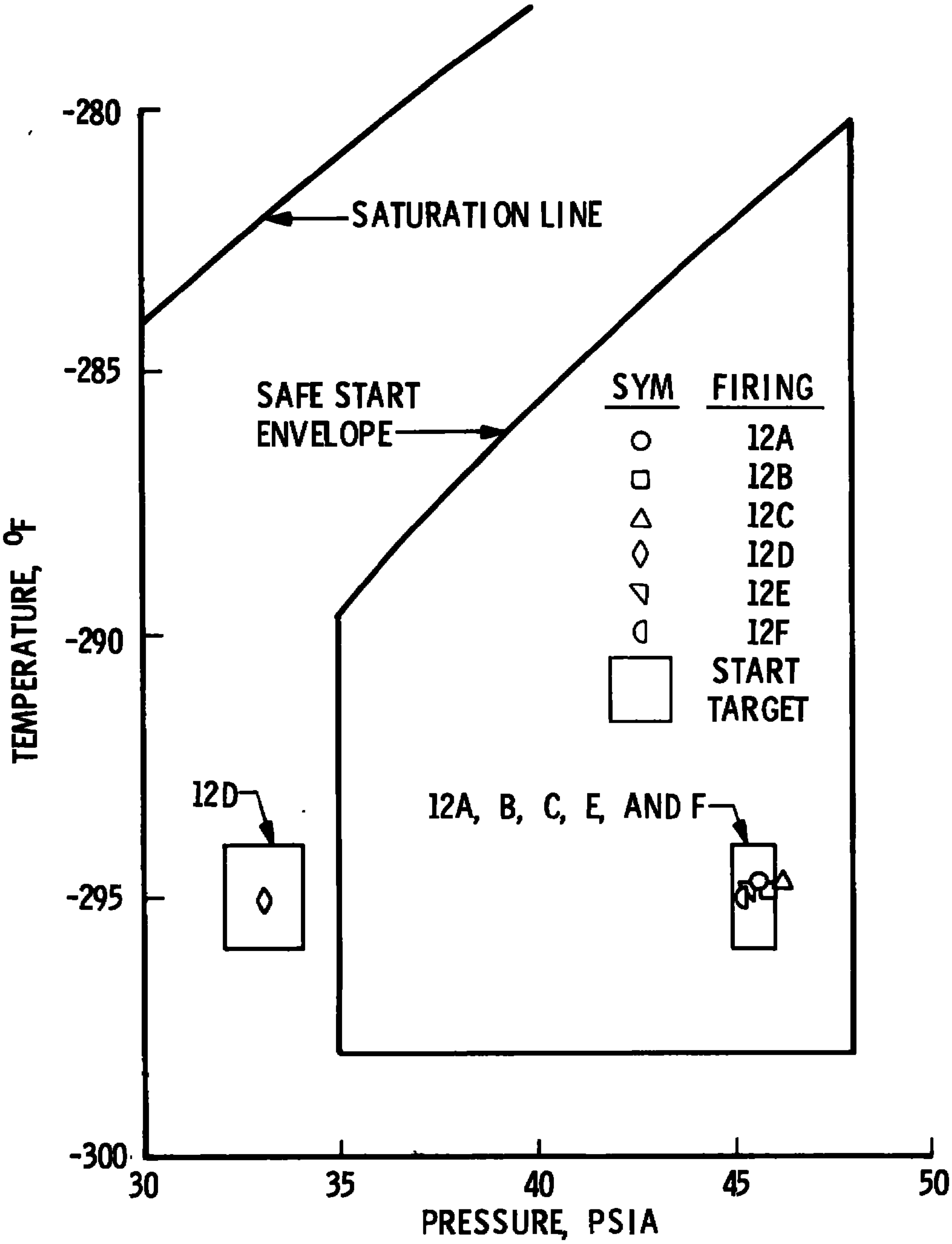
d. Auxiliary Logic Start Sequence

Fig. 7 Concluded

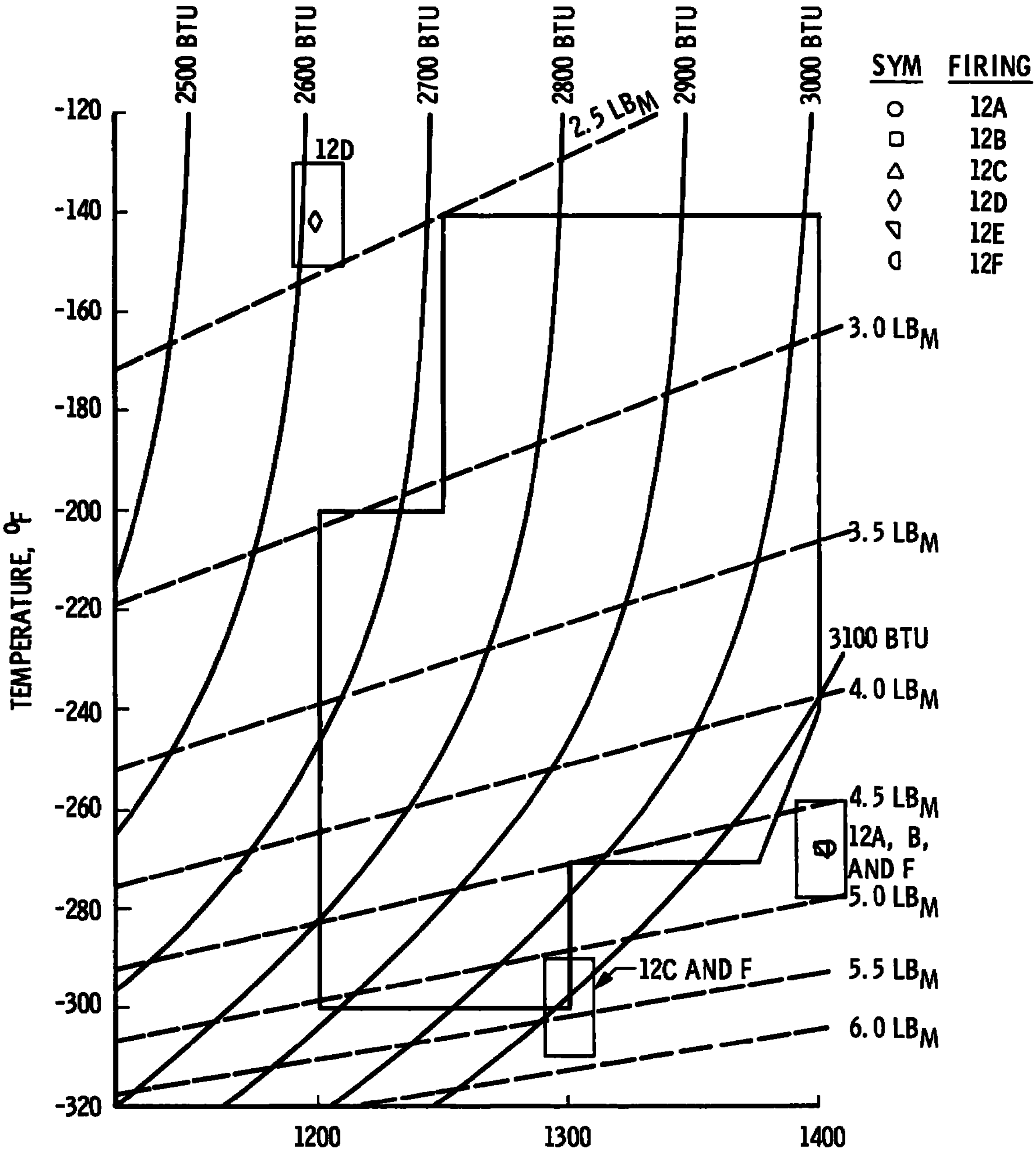


a. Fuel Pump Inlet

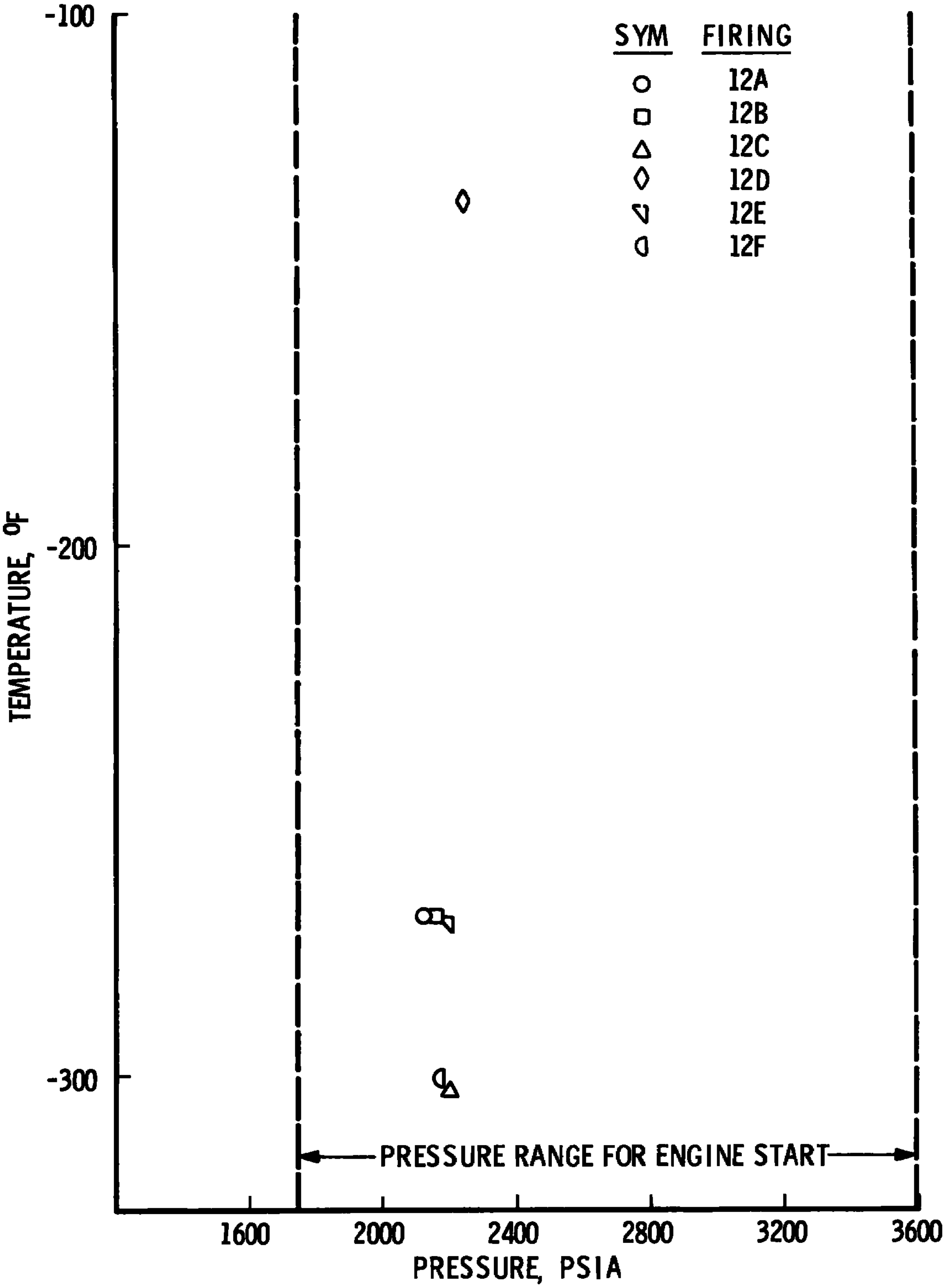
Fig. 8 Engine Start Conditions for Pump Inlets, Start Tank, and Helium Tank



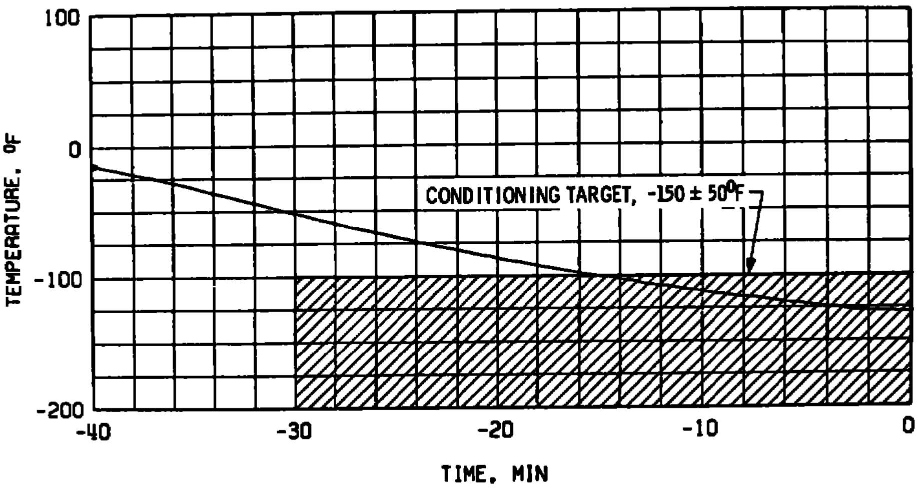
b. Oxidizer Pump Inlet
Fig. 8 Continued



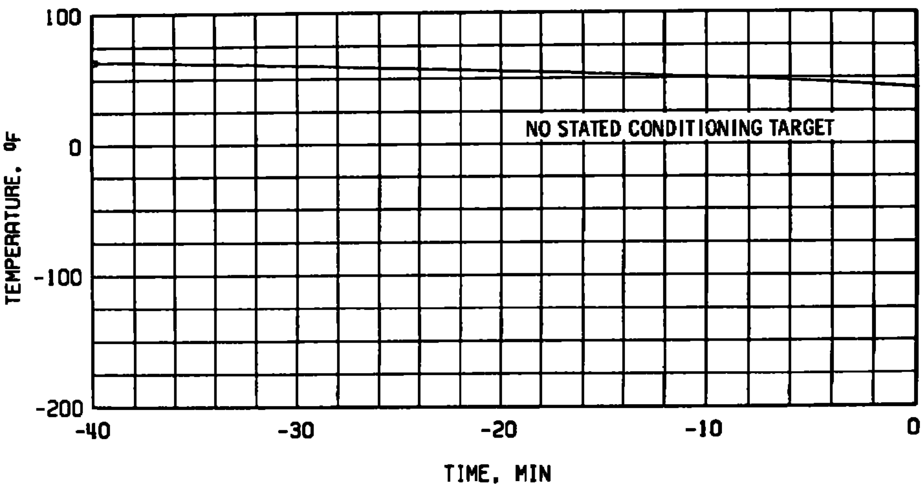
c. Start Tank
Fig. 8 Continued



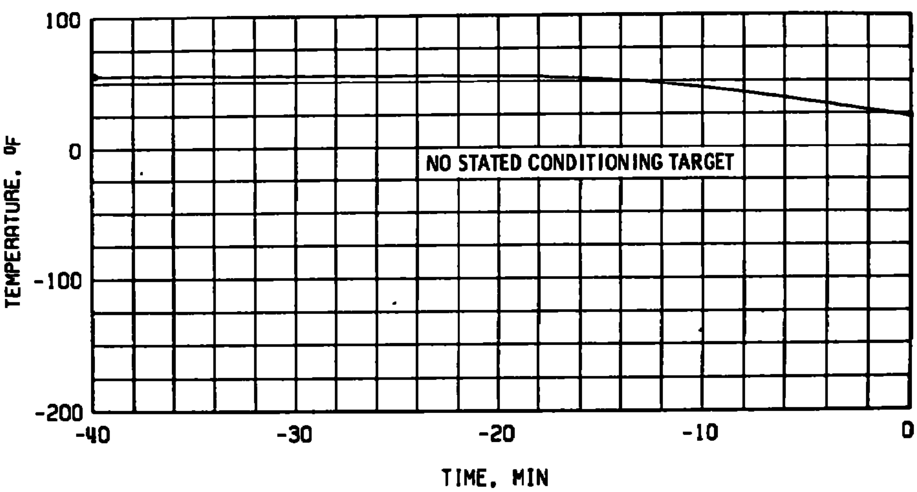
d. Helium Tank
Fig. 8 Concluded



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

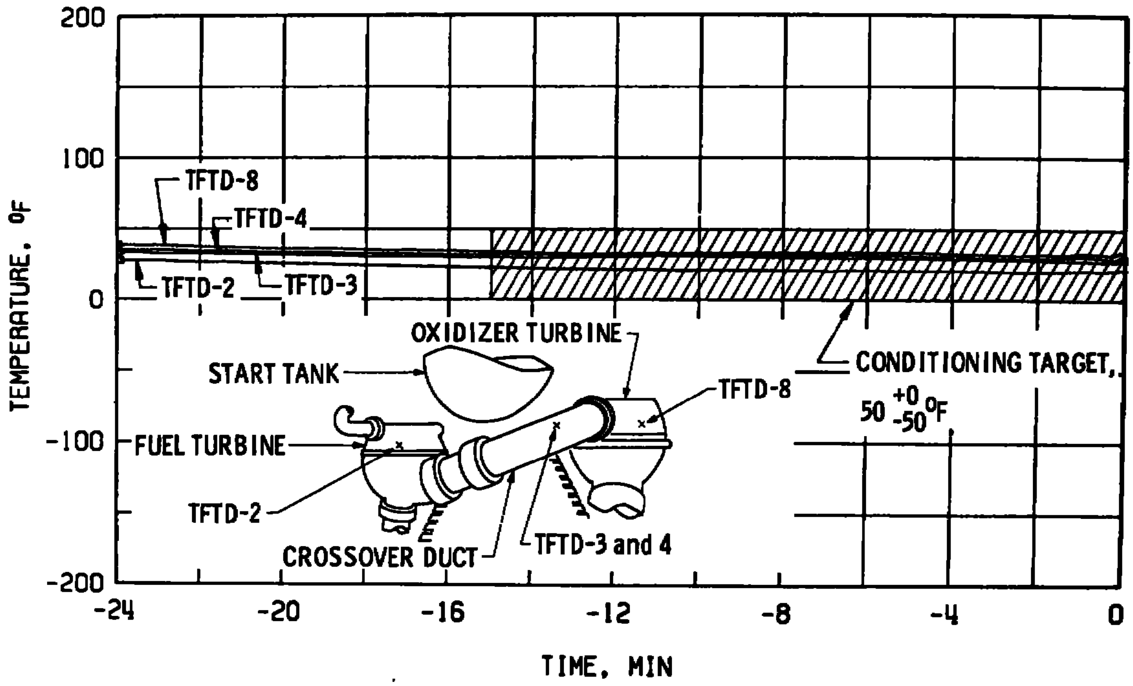


b. Gas Generator Body Temperature, TGGVRS

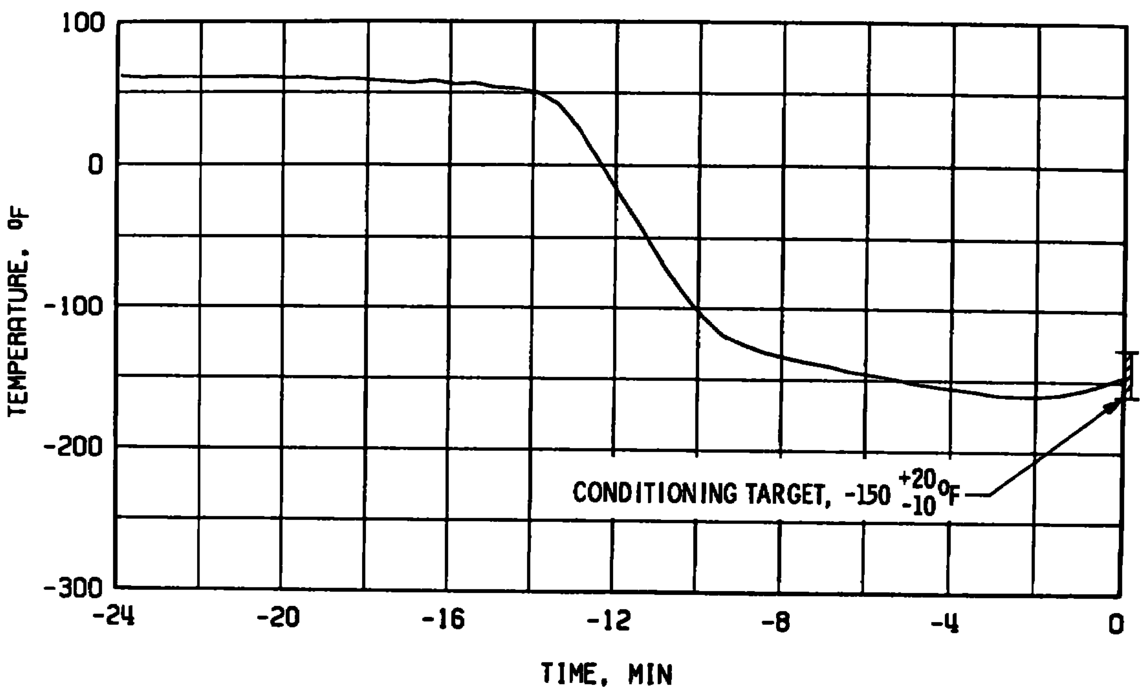


c. Start Tank Discharge Valve Opening Control Temperature, TSTDVOC

Fig. 9 Thermal Conditioning History of Engine Components, Firing 12A



d. Crossover Duct, TFTD



e. Thrust Chamber Throat, TTC-1P
Fig. 9 Concluded

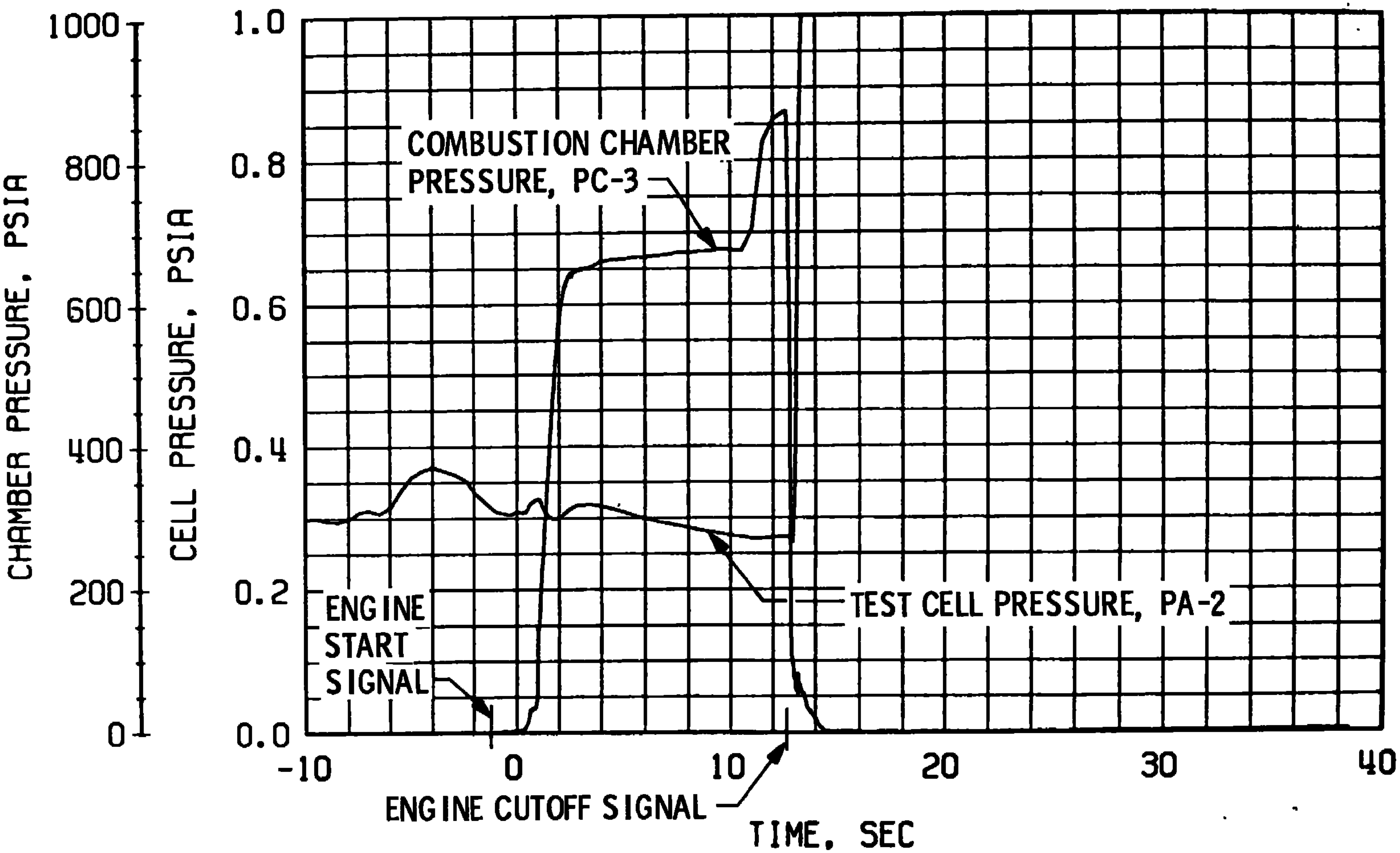
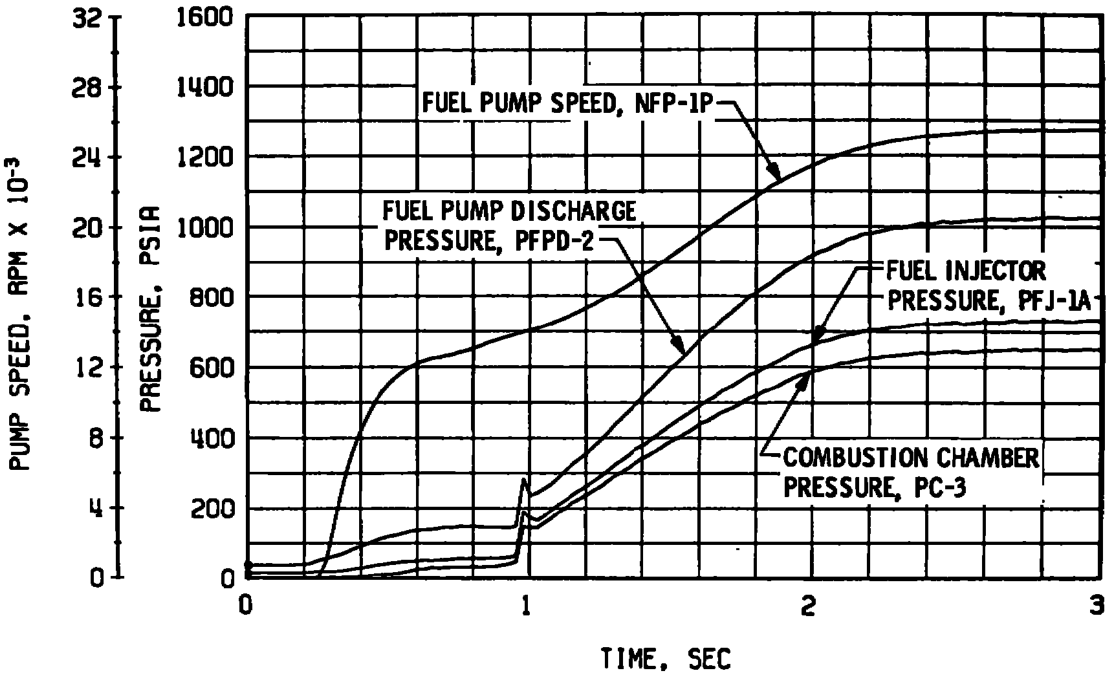
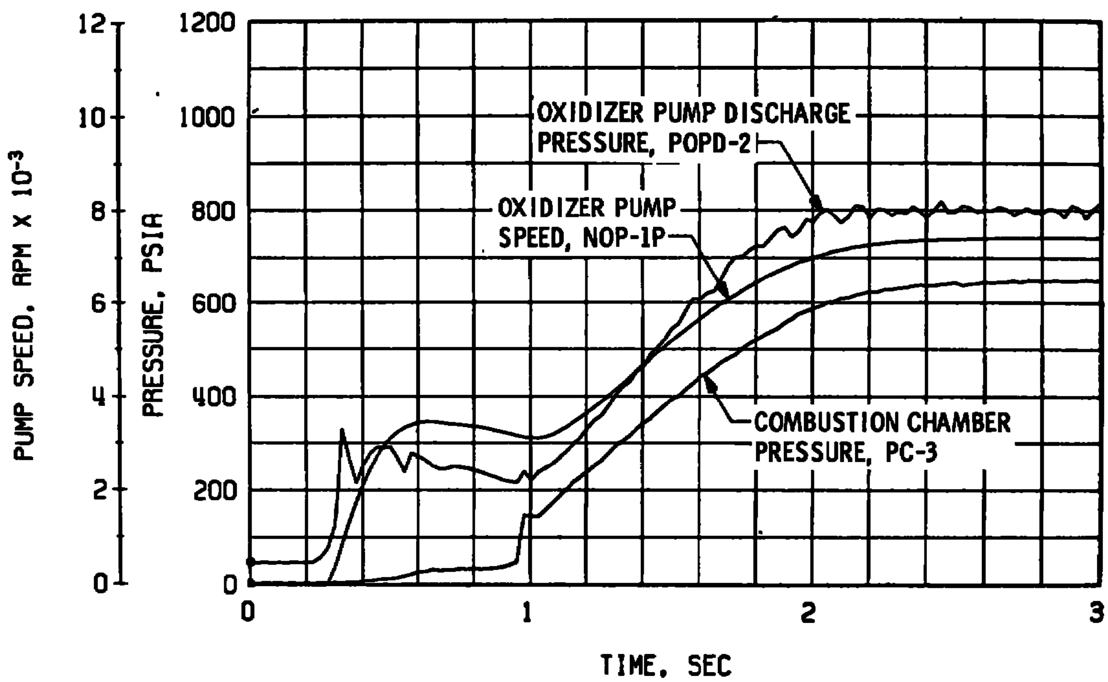


Fig. 10 Engine Ambient and Combustion Chamber Pressures, Firing 12A

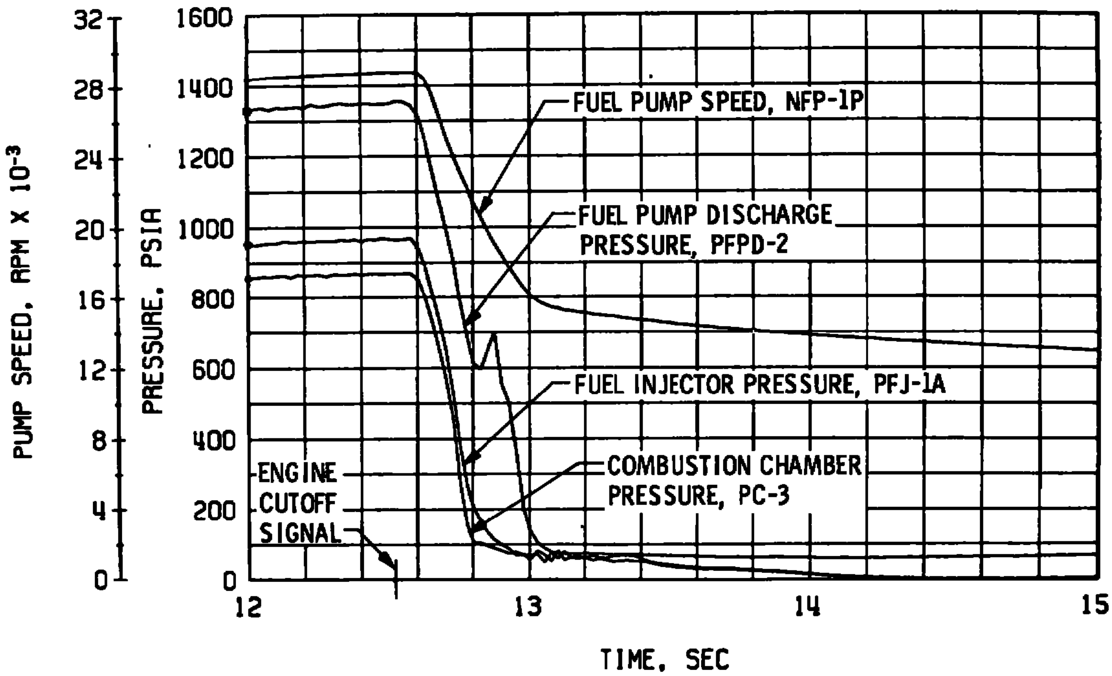


a. Thrust Chamber Fuel System, Start

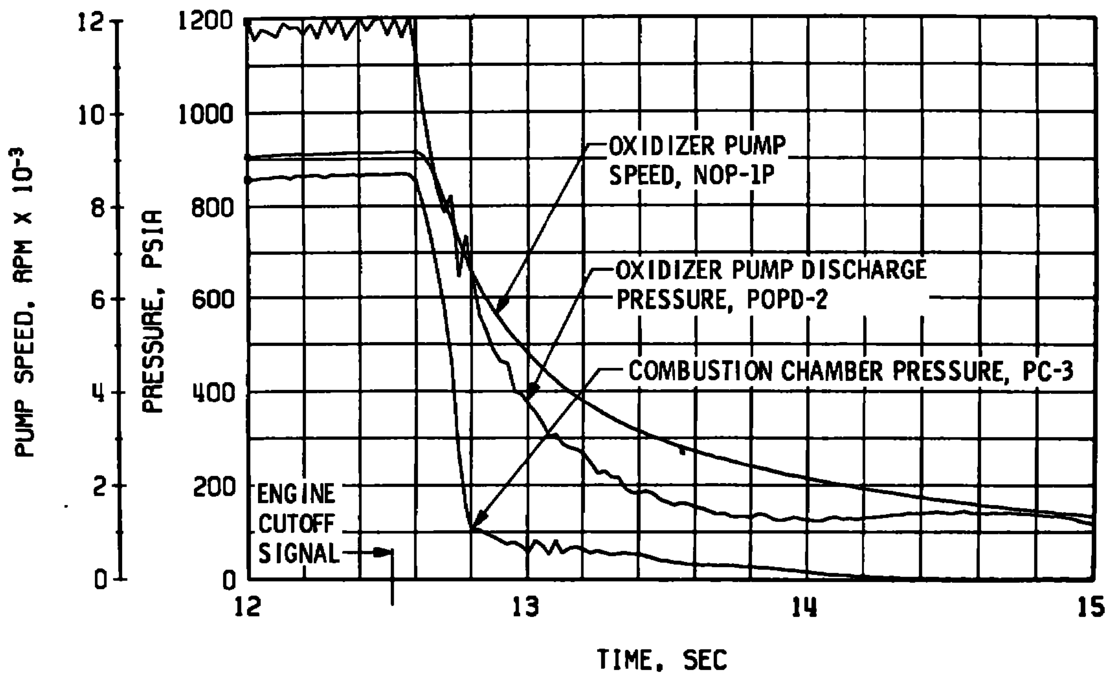


b. Thrust Chamber Oxidizer System, Start

Fig. 11 Engine Transient Operation, Firing 12A

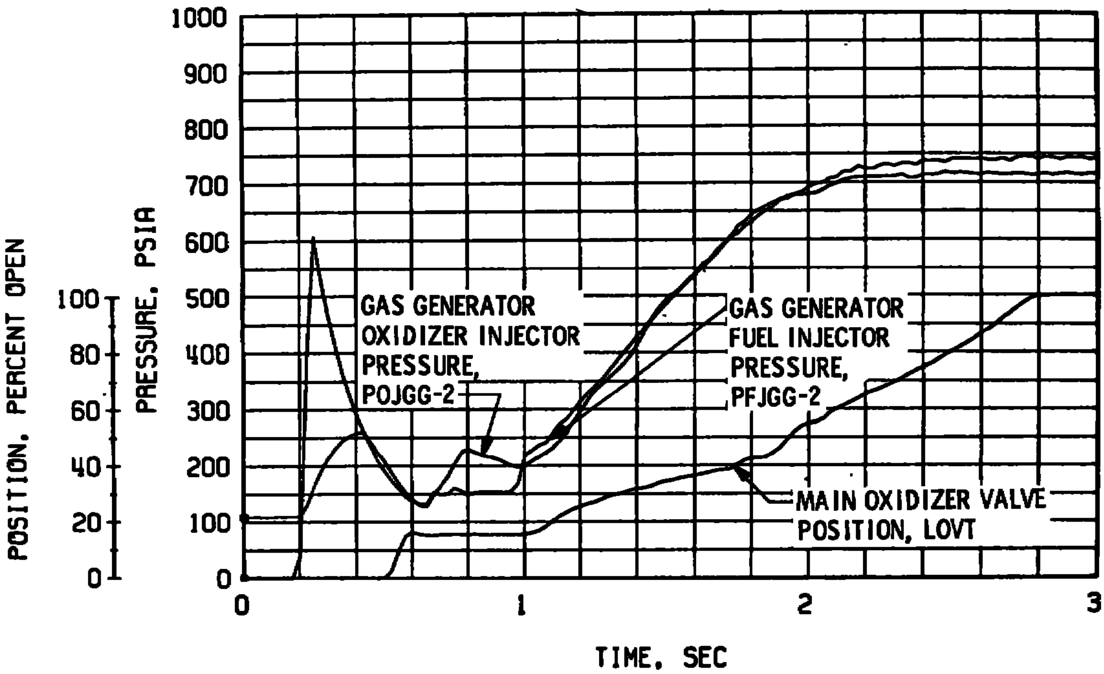


c. Thrust Chamber Fuel System, Shutdown

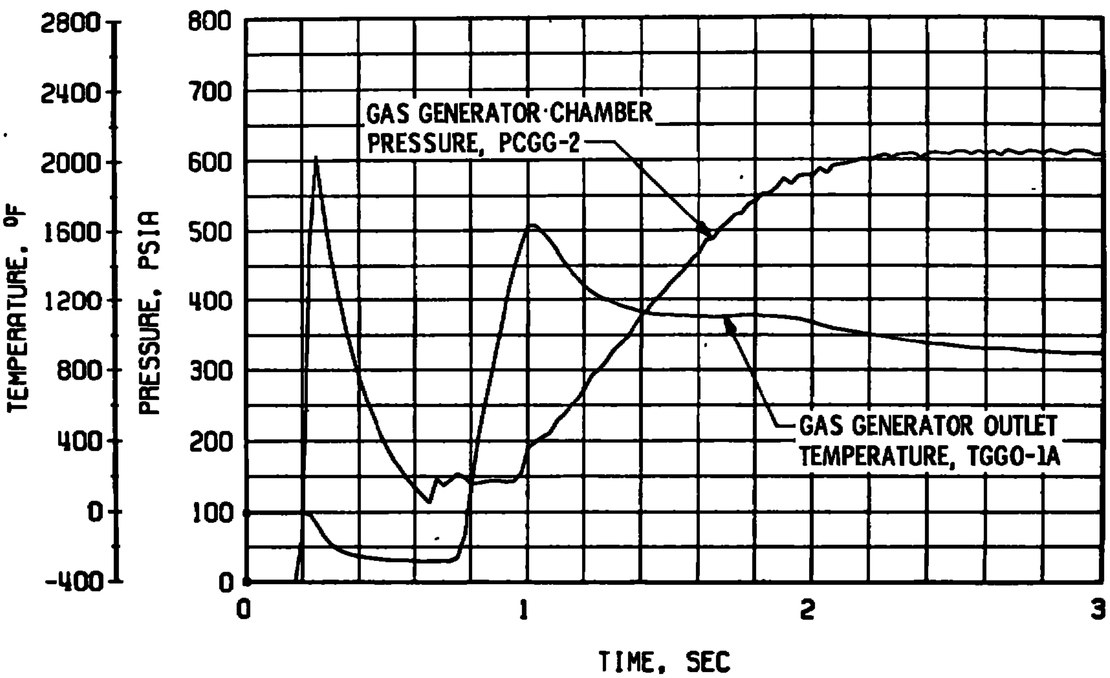


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 11 Continued

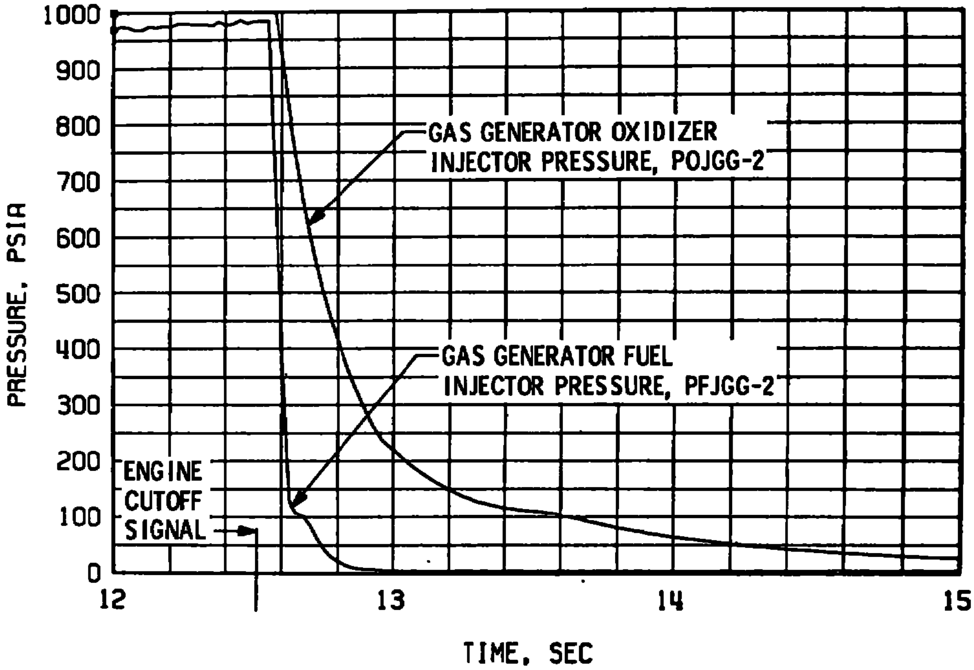


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

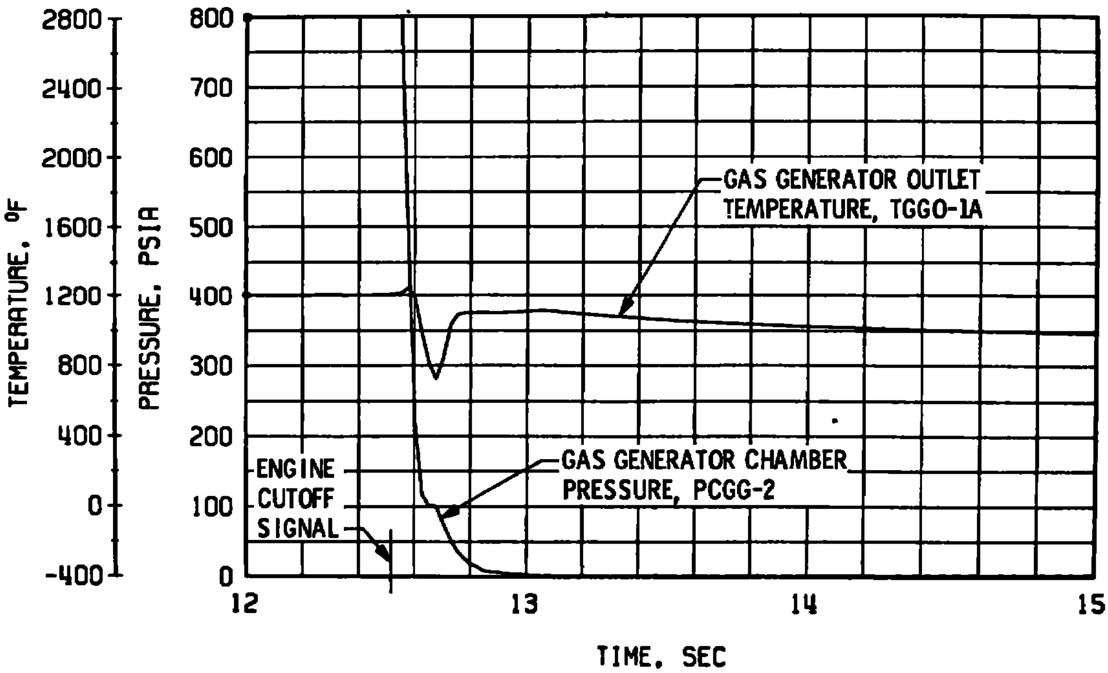


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 11 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown
Fig. 11 Concluded

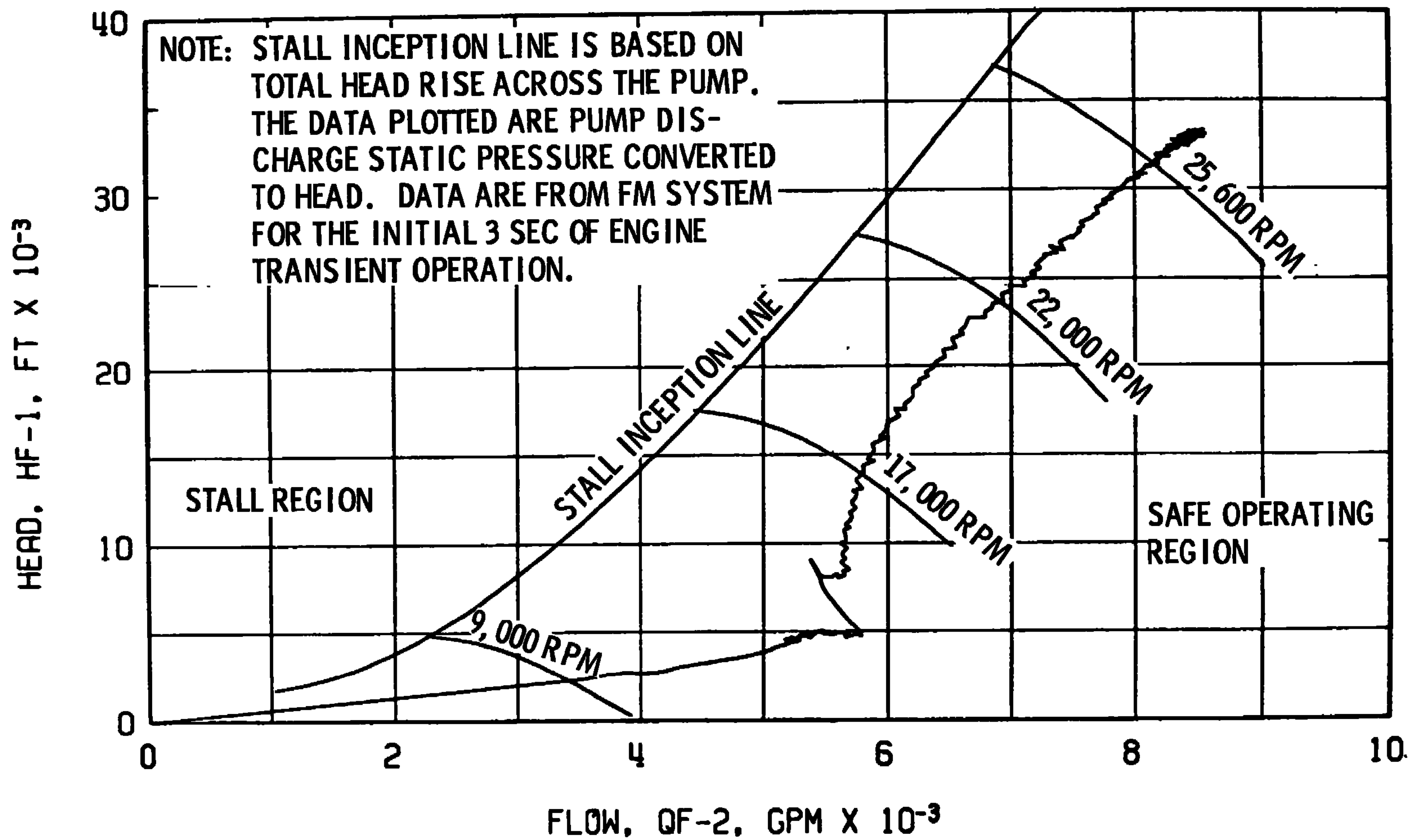
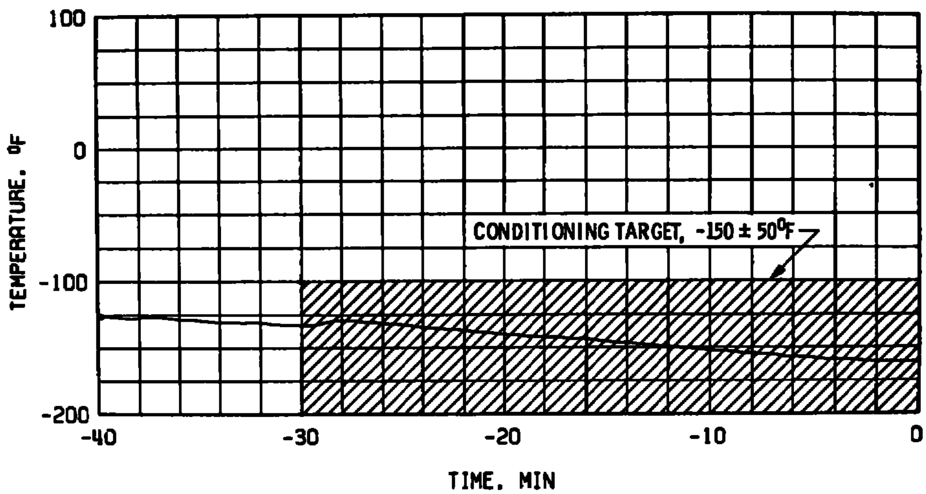
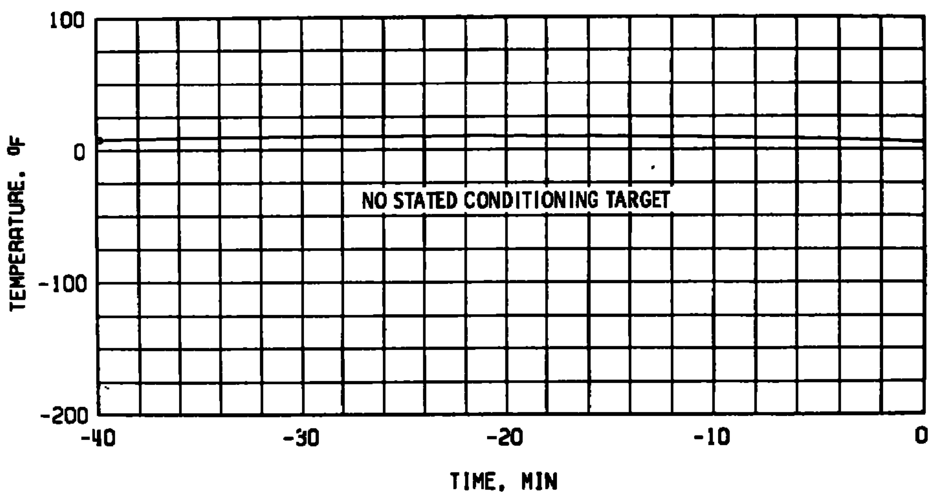


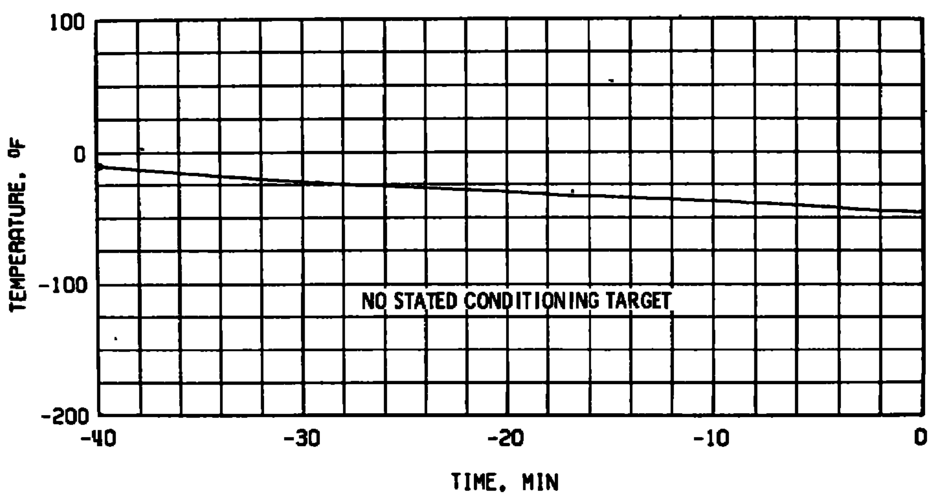
Fig. 12 Fuel Pump Start Transient Performance, Firing 12A



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

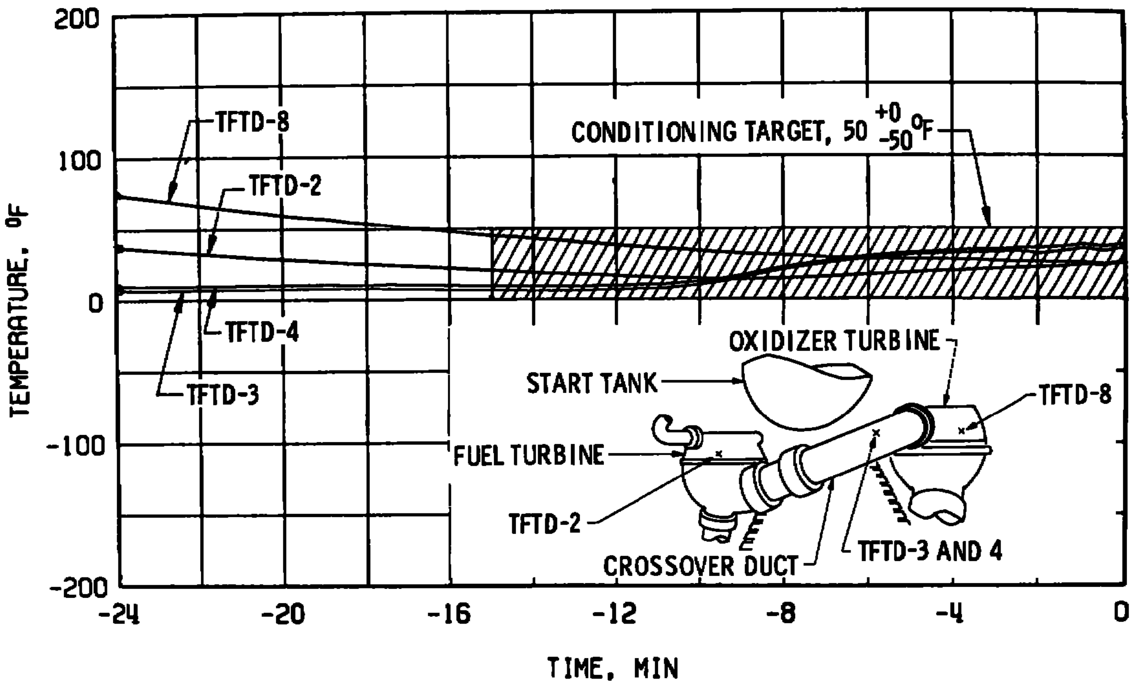


b. Gas Generator Body Temperature, TGGVRS

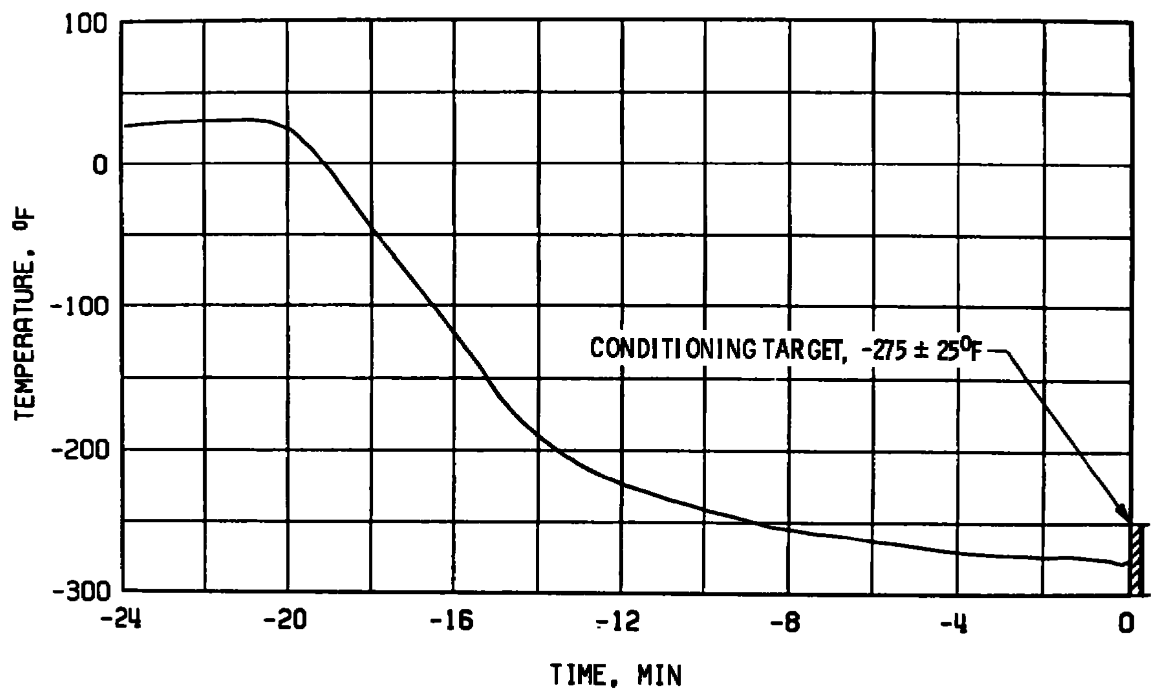


c. Start Tank Discharge Valve Opening Control Temperature, TSTDVOC

Fig. 13 Thermal Conditioning History of Engine Components, Firing 12B



d. Crossover Duct, TFTD



e. Thrust Chamber Throat, TTC-1P

Fig. 13 Concluded

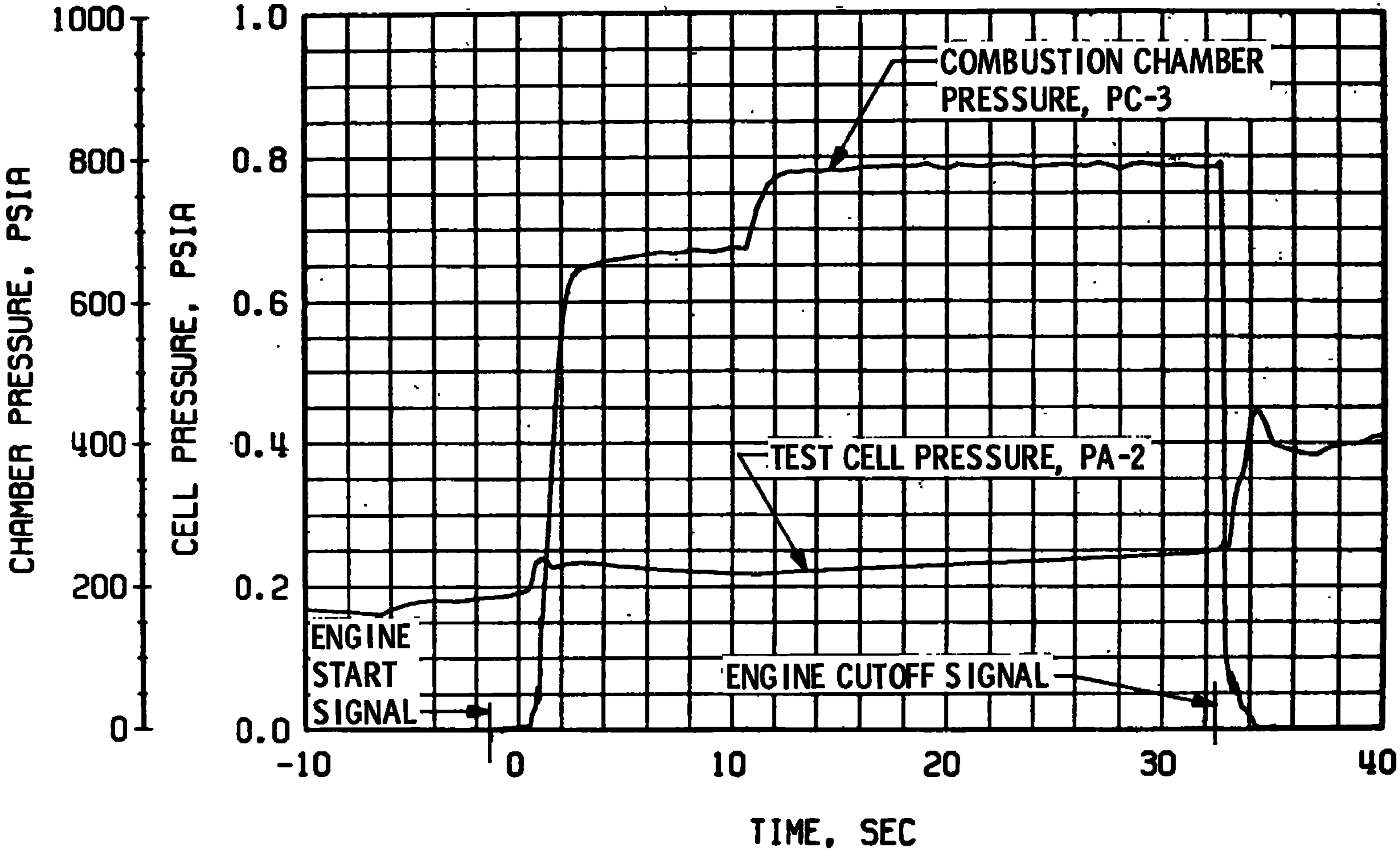
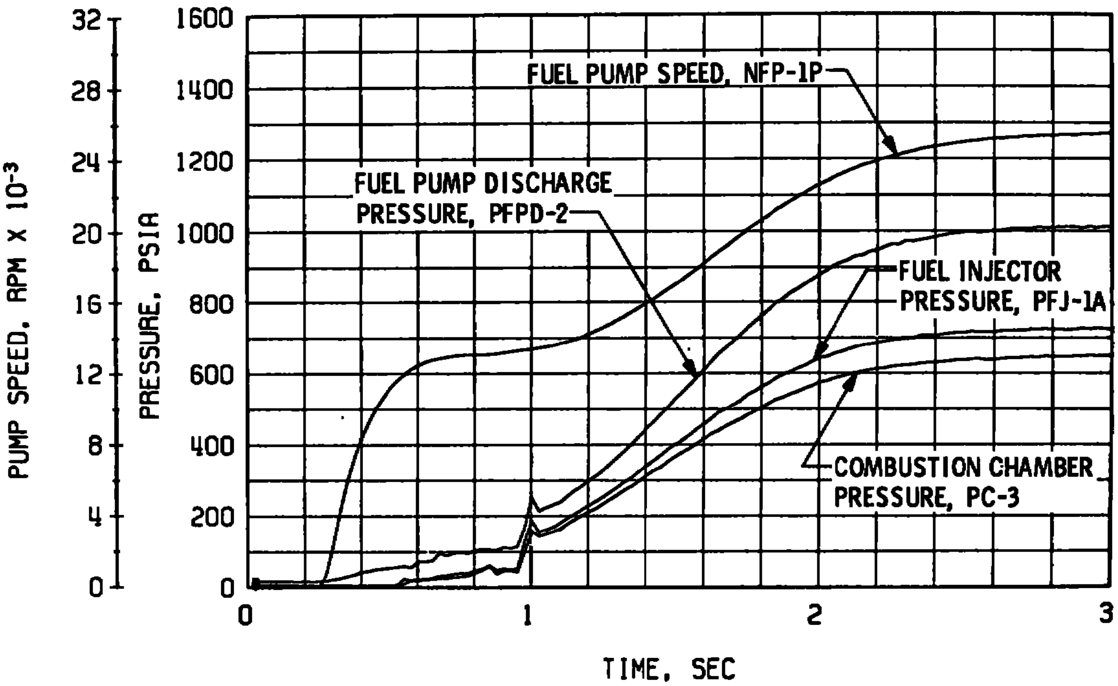
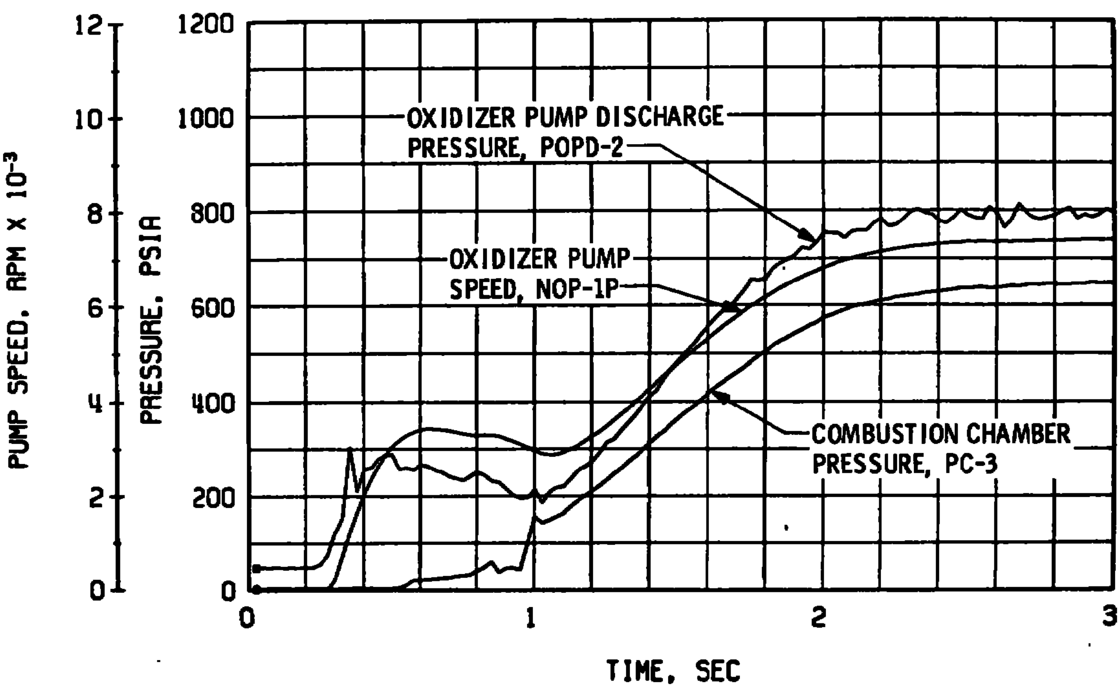


Fig. 14 Engine Ambient and Combustion Chamber Pressures, Firing 12B

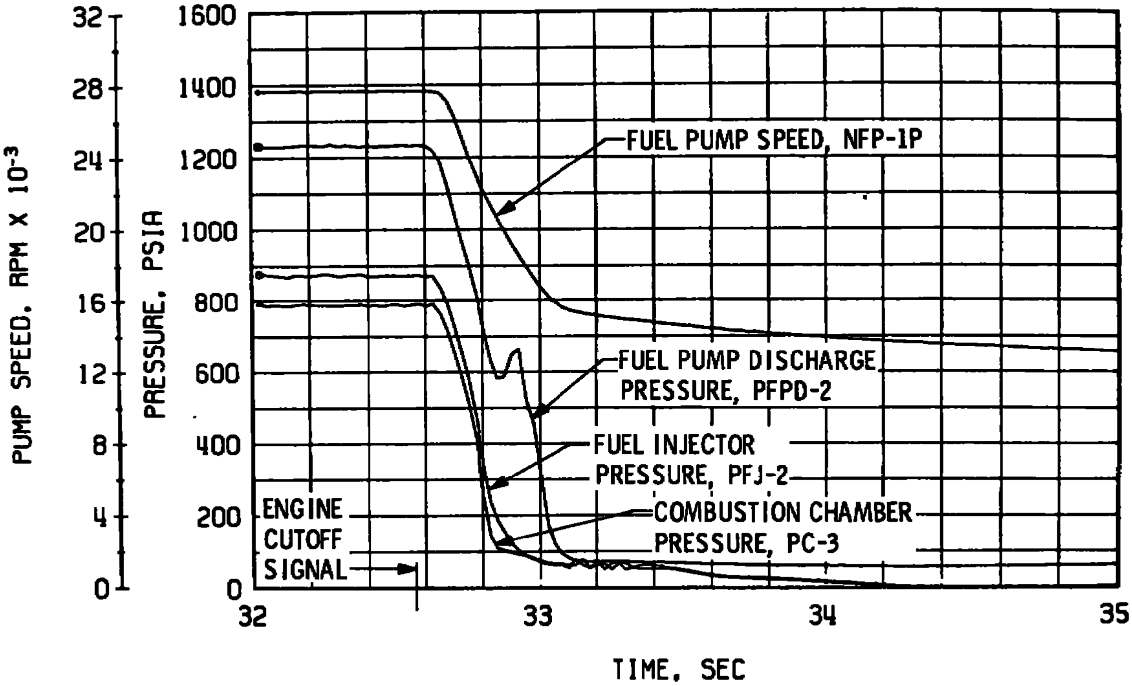


a. Thrust Chamber Fuel System, Start

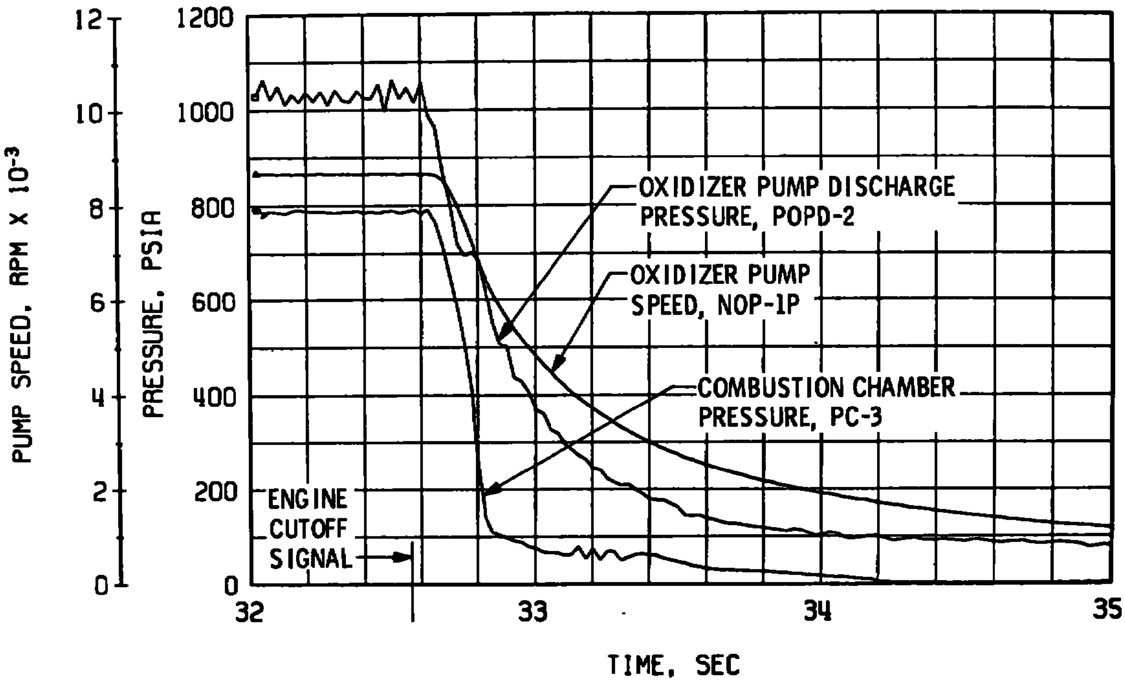


b. Thrust Chamber Oxidizer System, Start

Fig. 15 Engine Transient Operation, Firing 12B

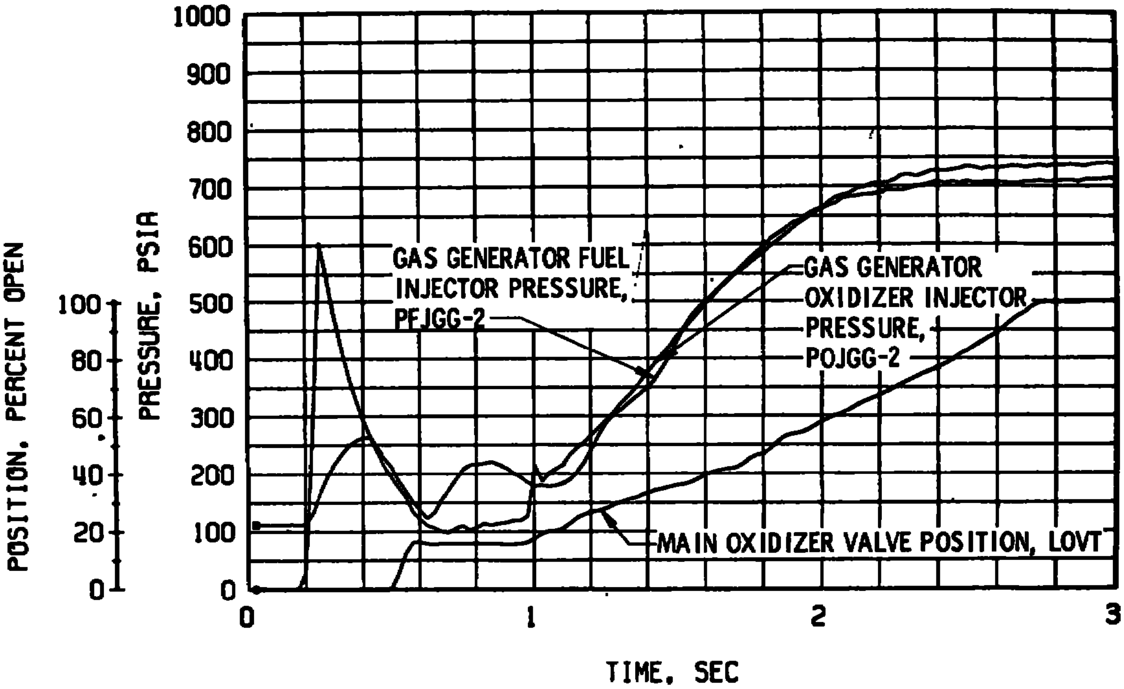


c. Thrust Chamber Fuel System, Shutdown

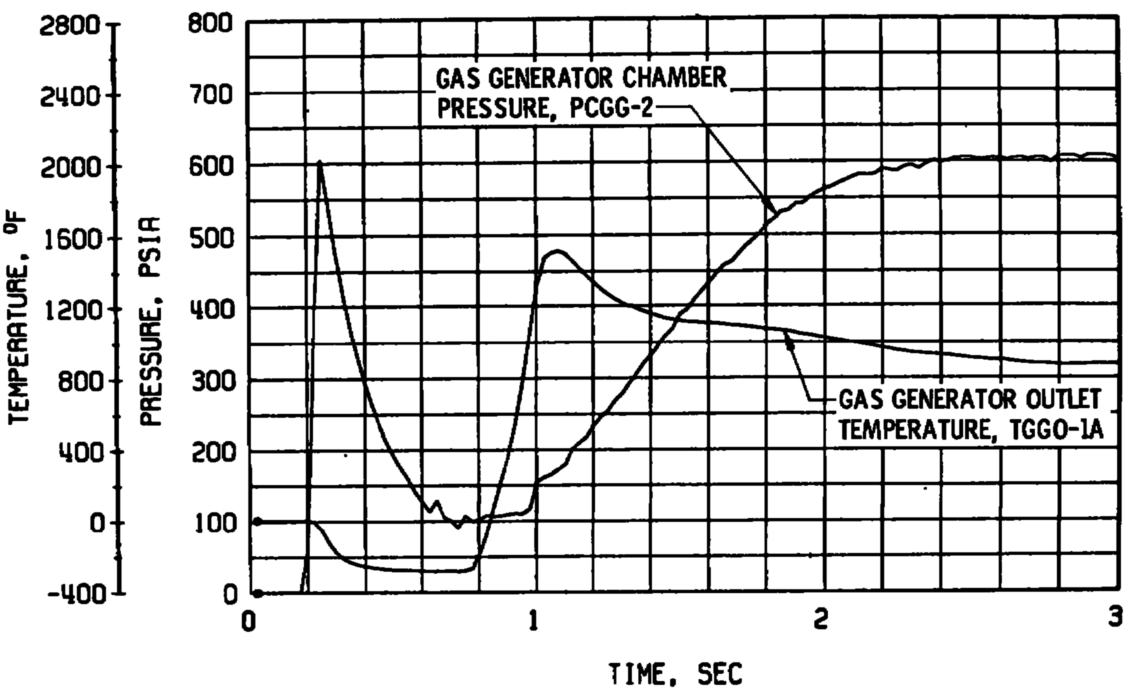


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 15 Continued

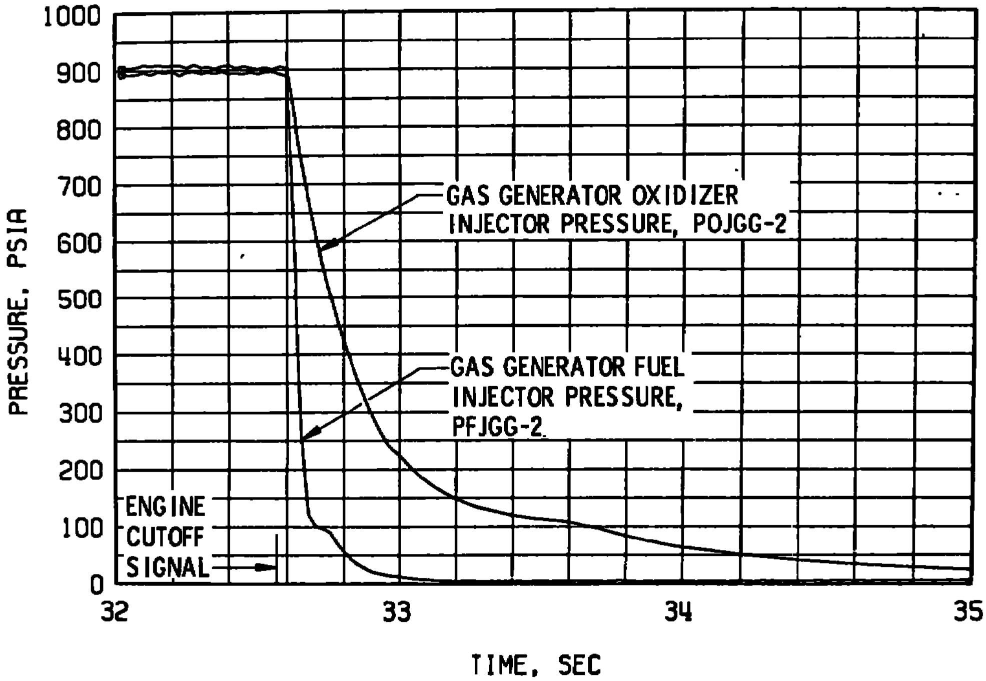


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

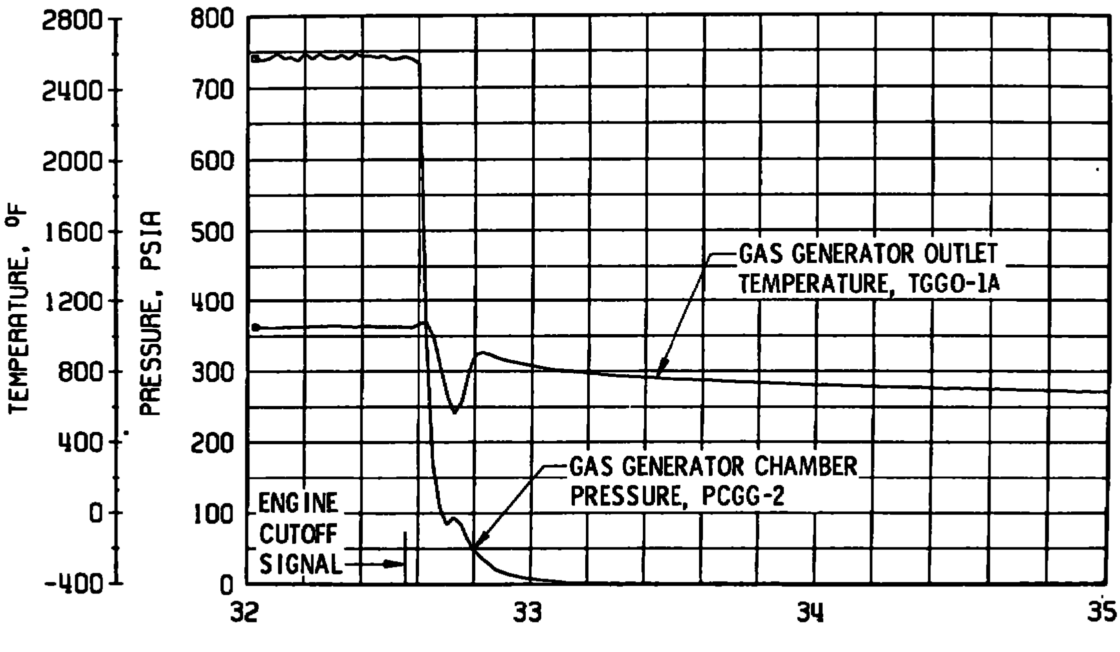


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 15 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown
Fig. 15 Concluded

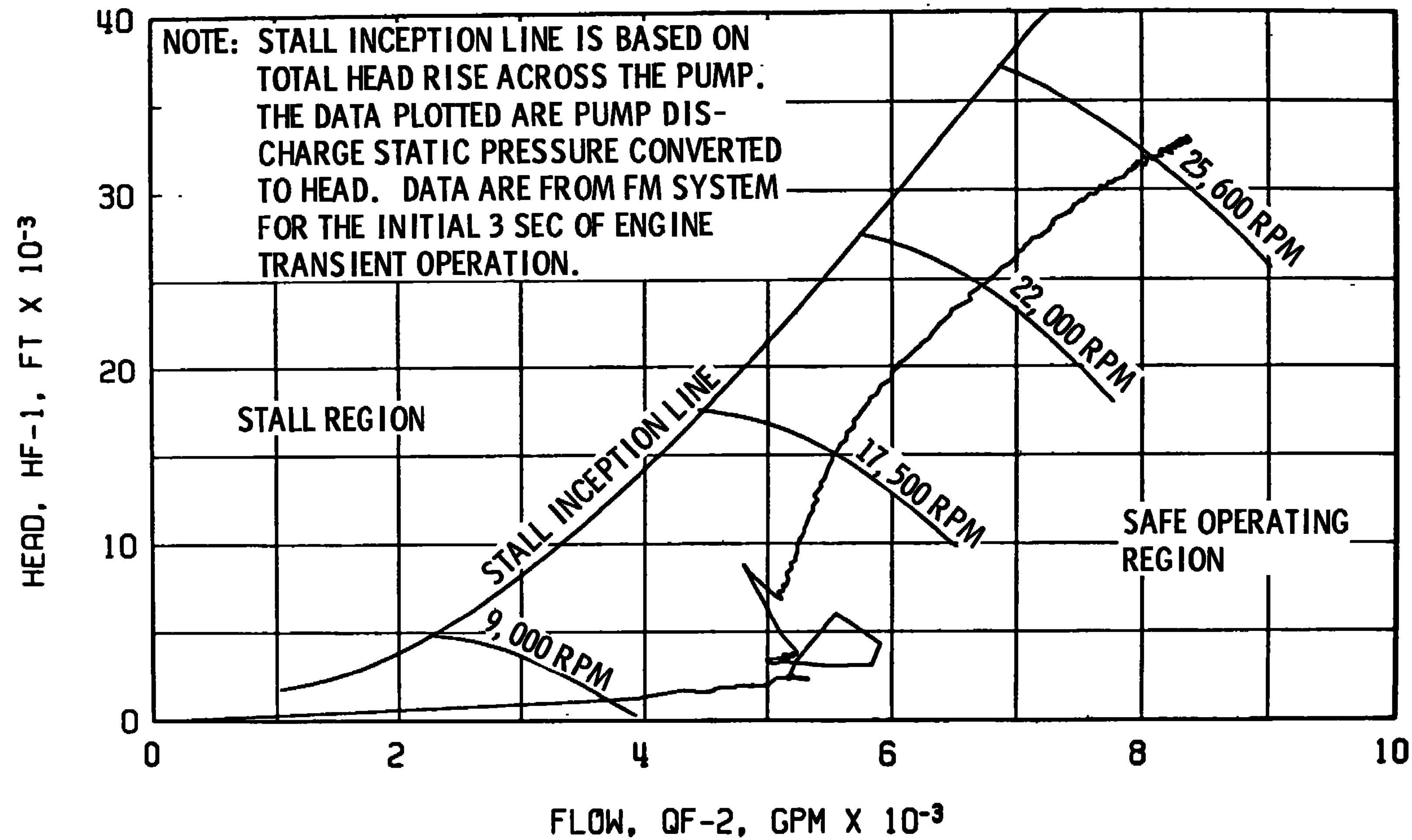
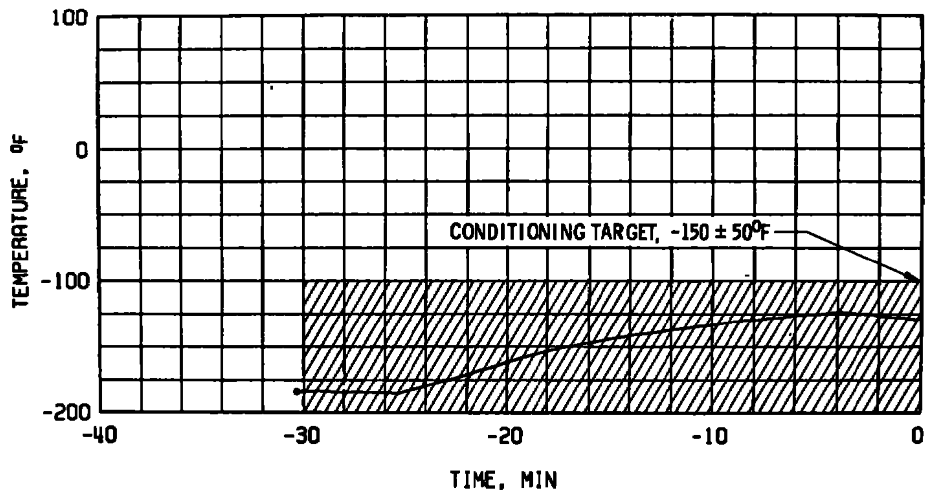
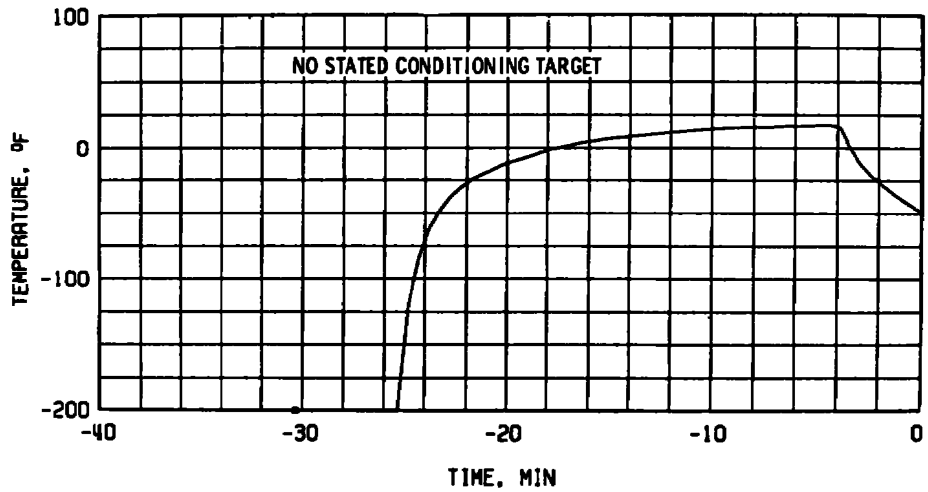


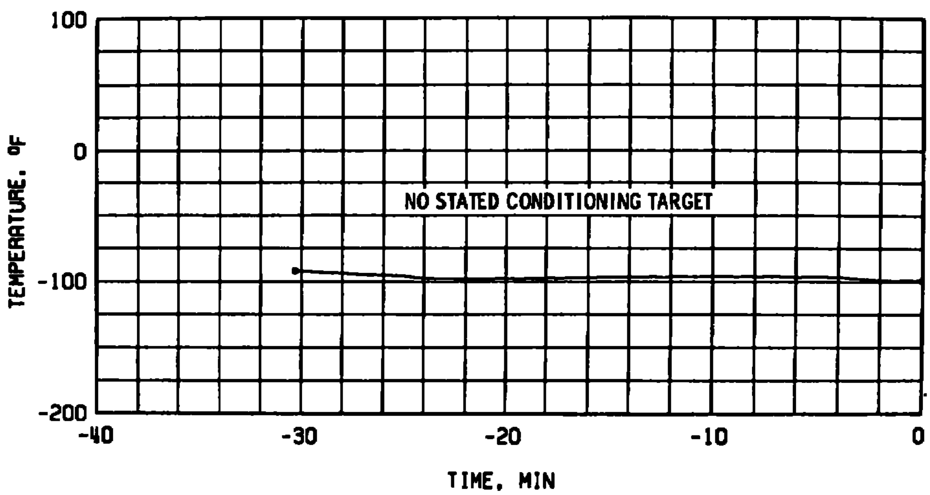
Fig. 16 Fuel Pump Start Transient Performance, Firing 12B



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

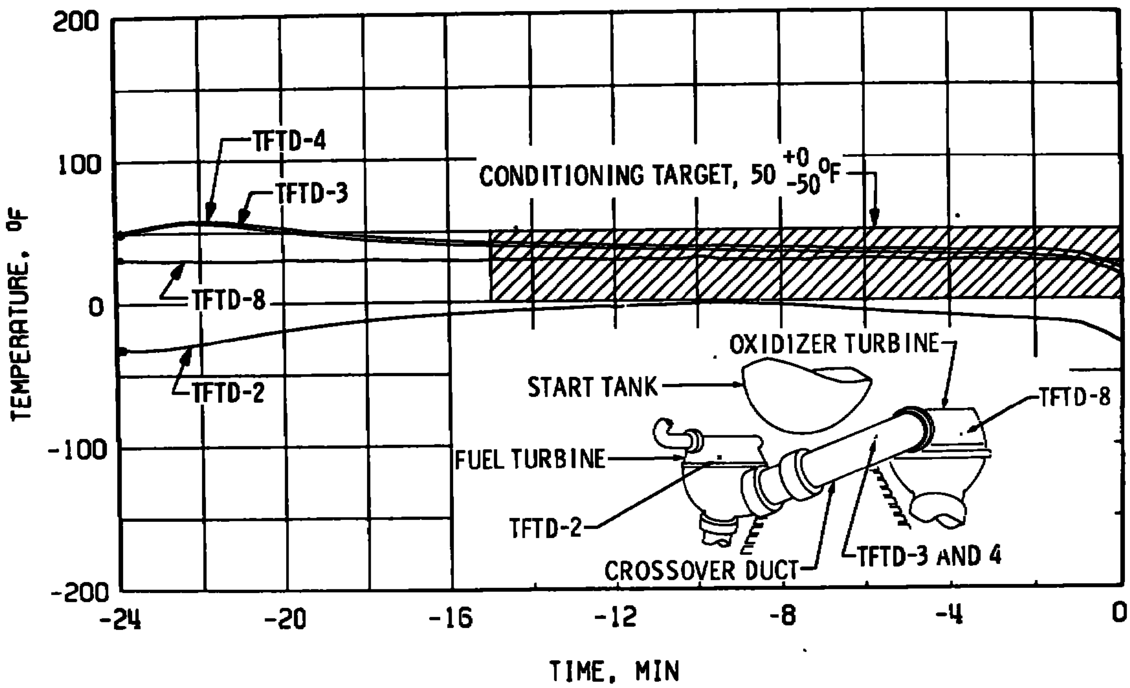


b. Gas Generator Body Temperature, TGGVRS

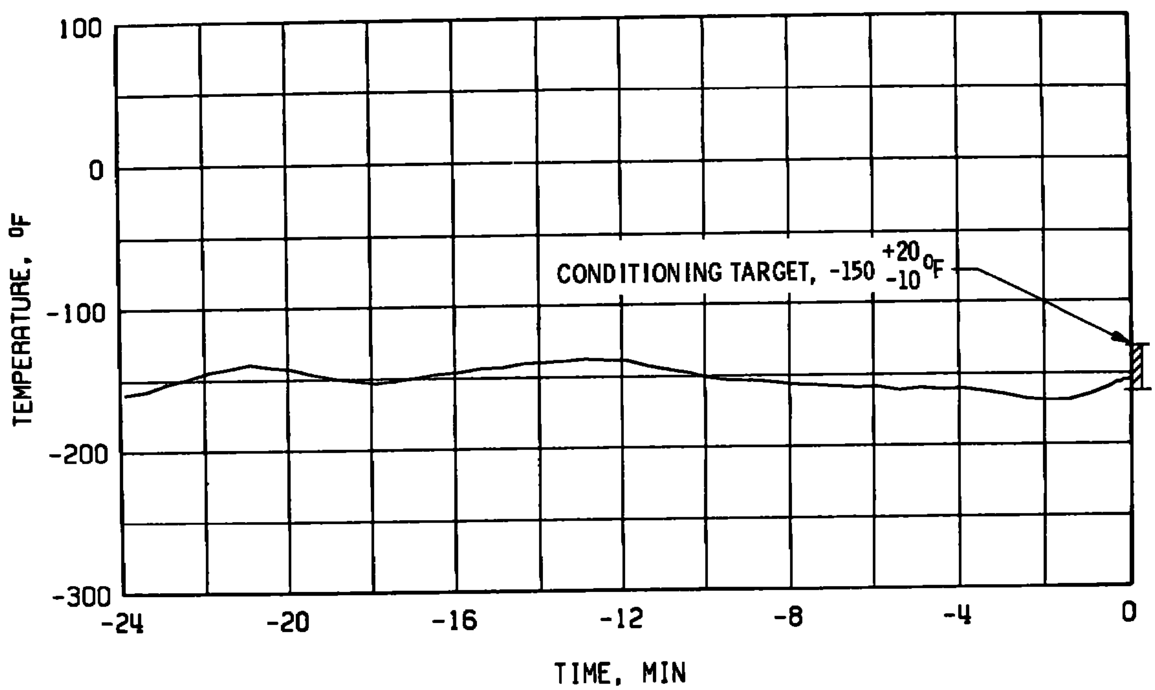


c. Start Tank Discharge Valve Opening Control Temperature, TSTDVOC

Fig. 17 Thermal Conditioning History of Engine Components, Firing 12C



d. Crossover Duct, TFTD



e. Thrust Chamber Throat, TTC-1P

Fig. 17 Concluded

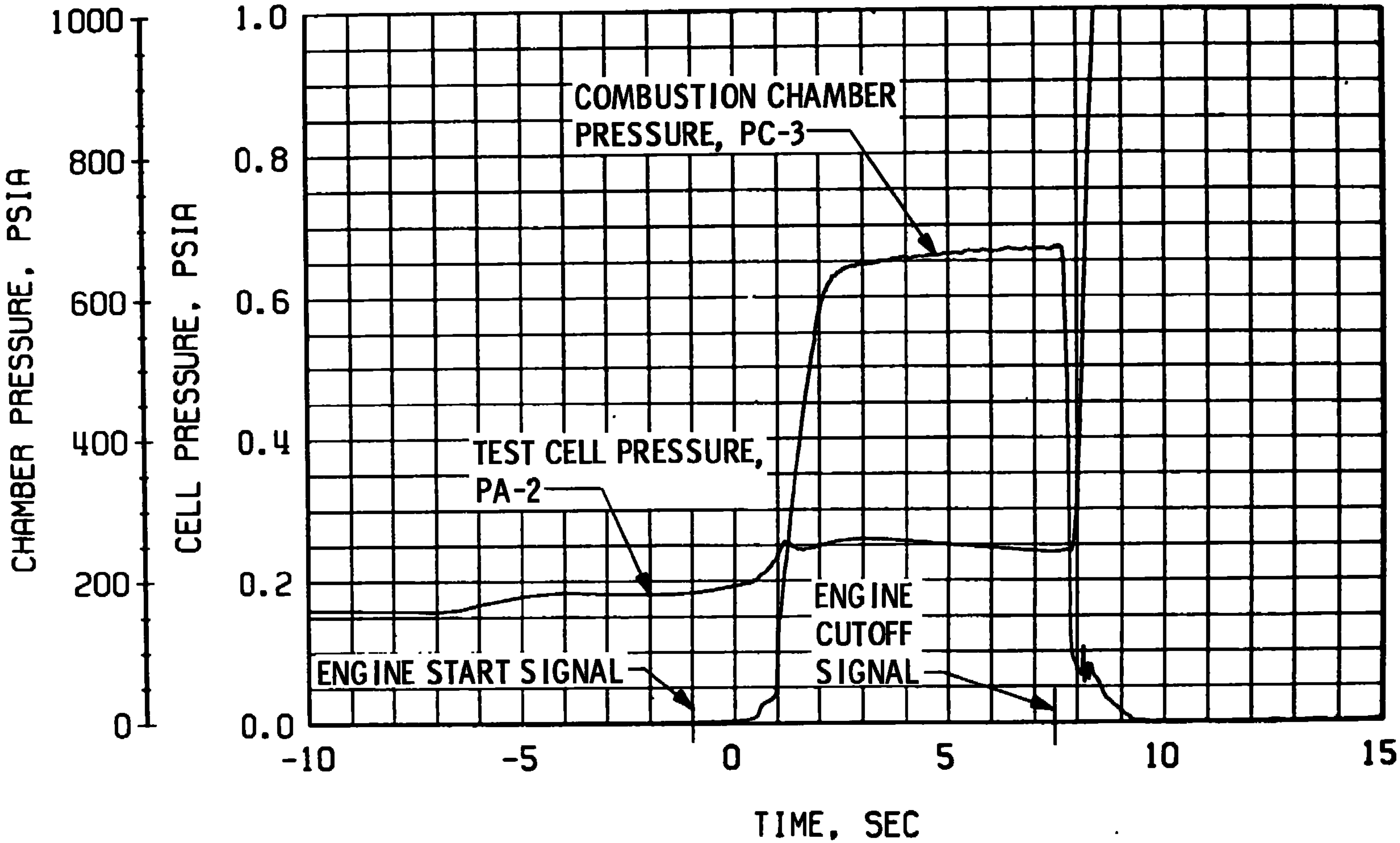
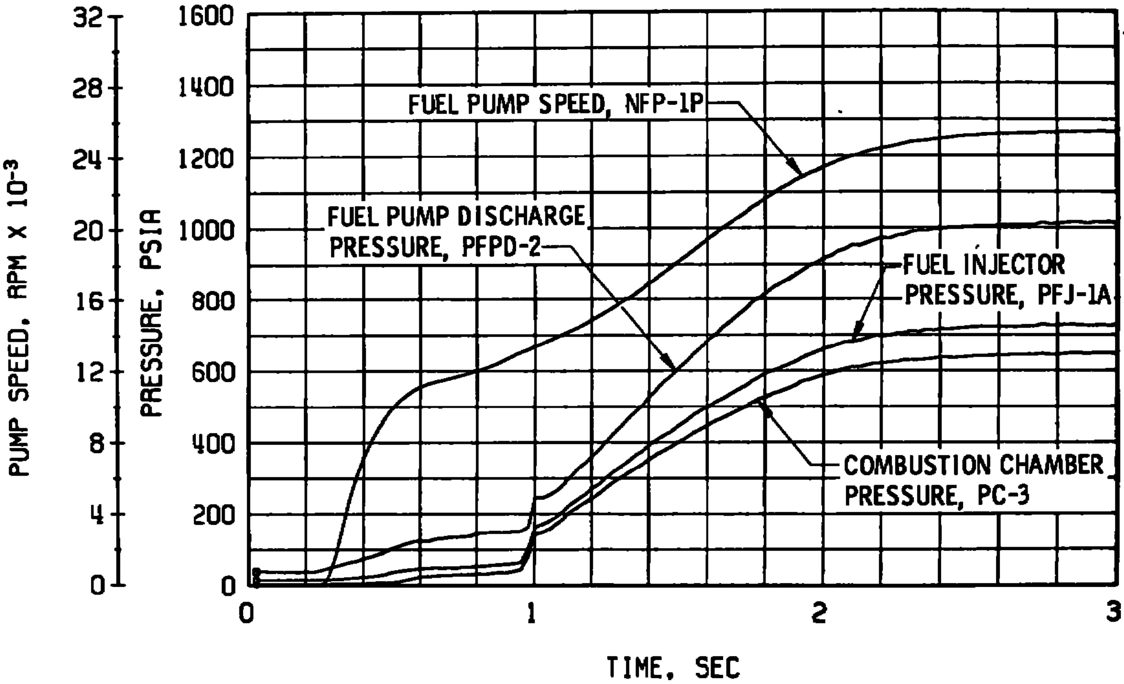
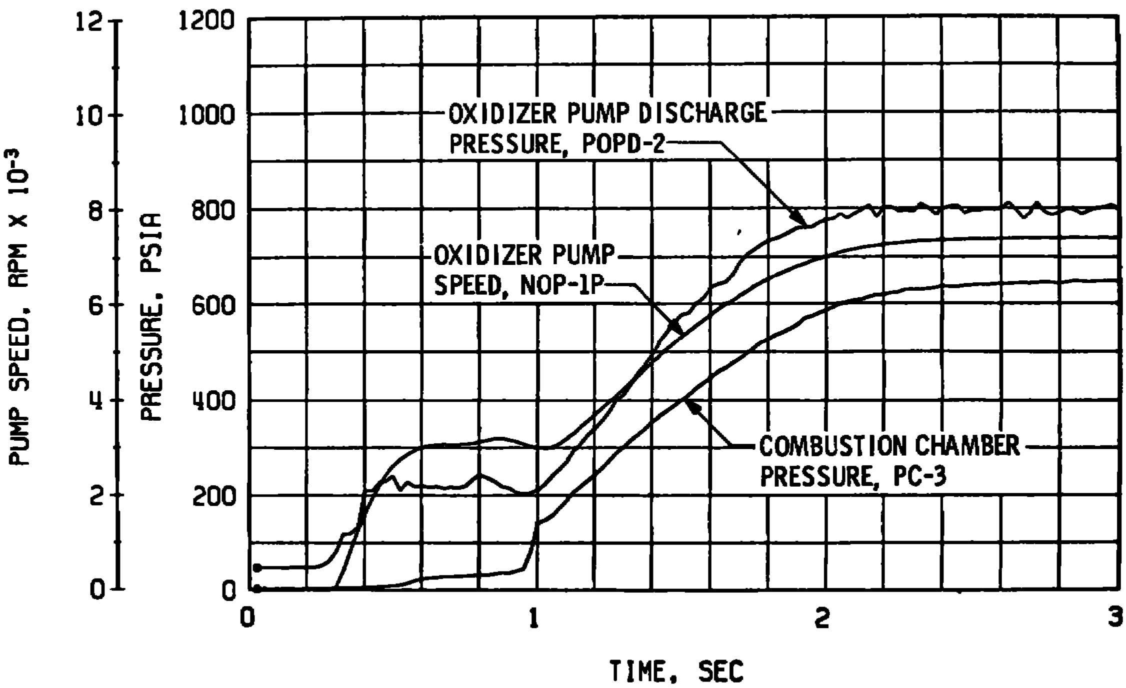


Fig. 18 Engine Ambient and Combustion Chamber Pressures, Firing 12C

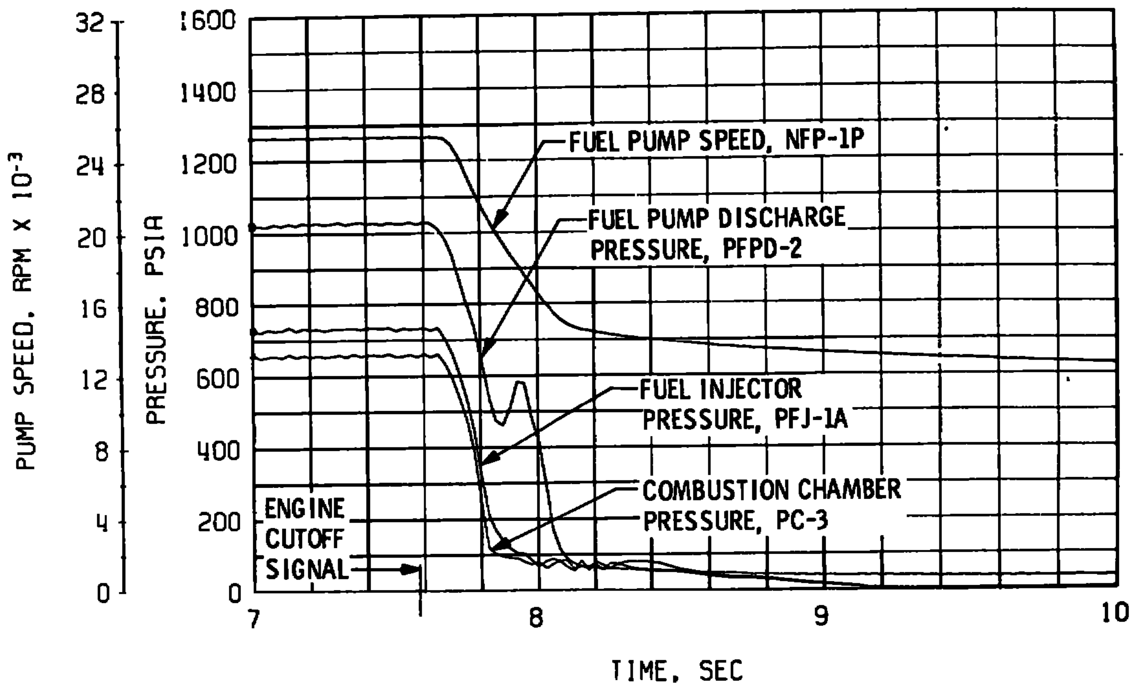


a. Thrust Chamber Fuel System, Start

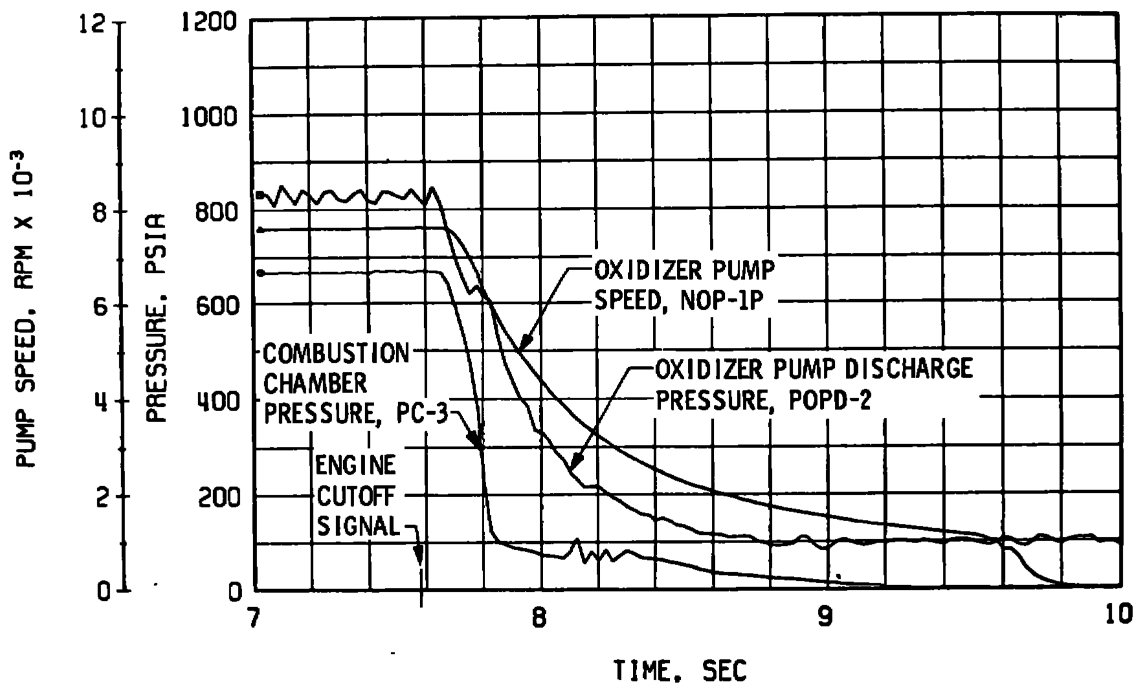


b. Thrust Chamber Oxidizer System, Start

Fig. 19 Engine Transient Operation, Firing 12C

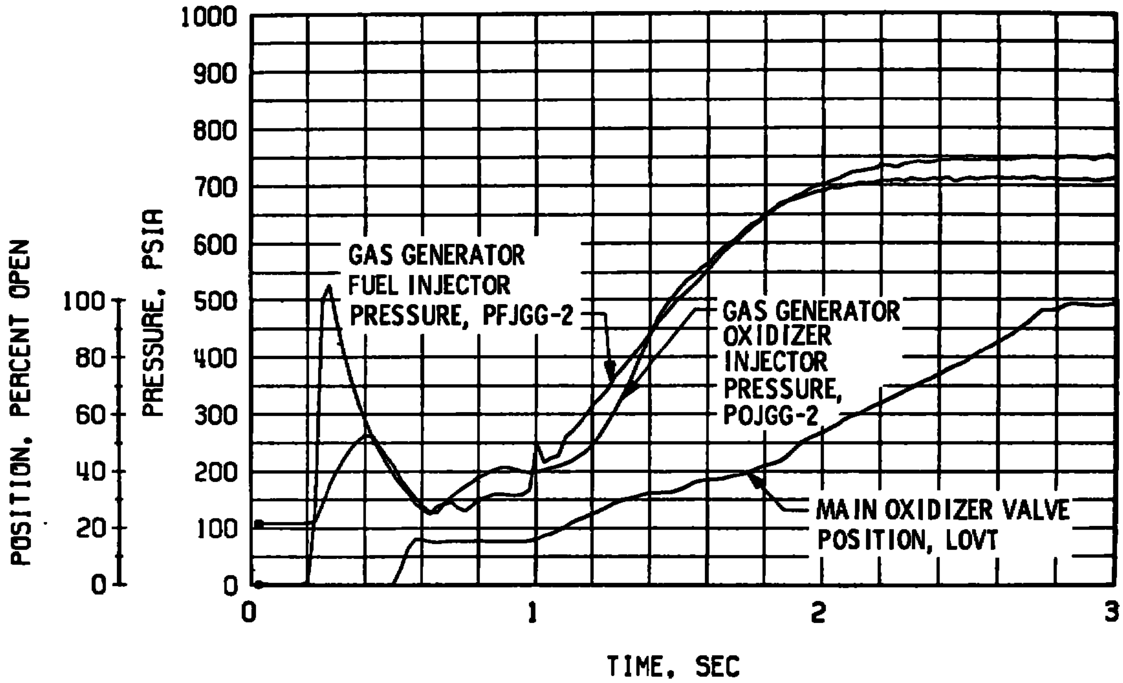


c. Thrust Chamber Oxidizer System, Shutdown

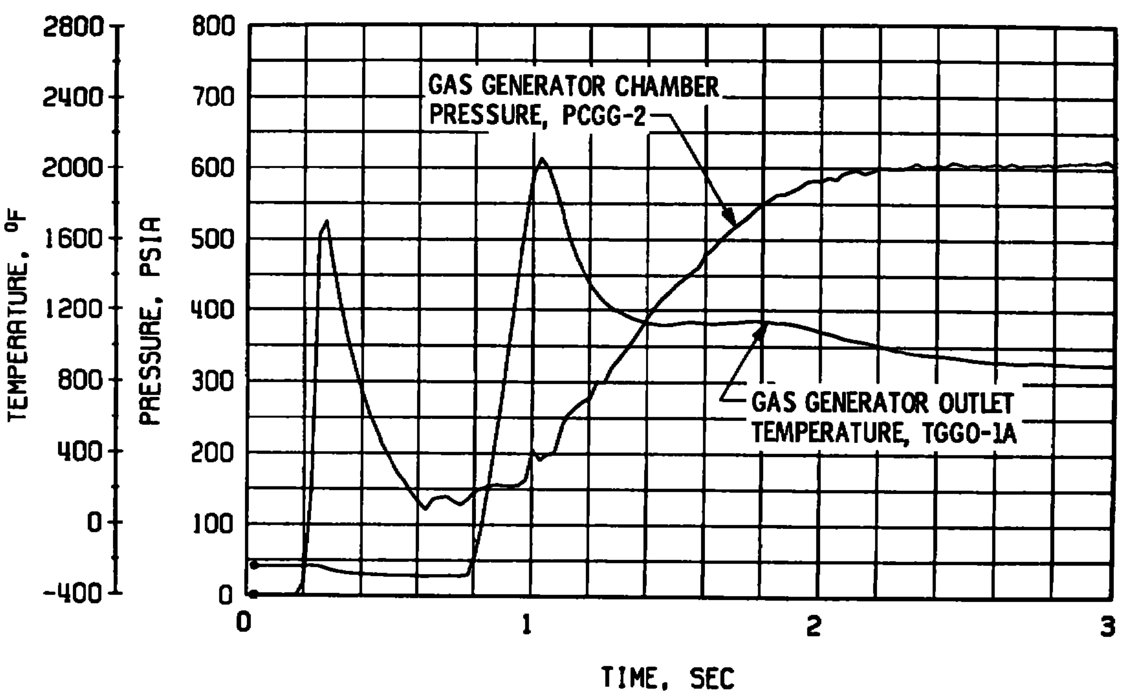


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 19 Continued

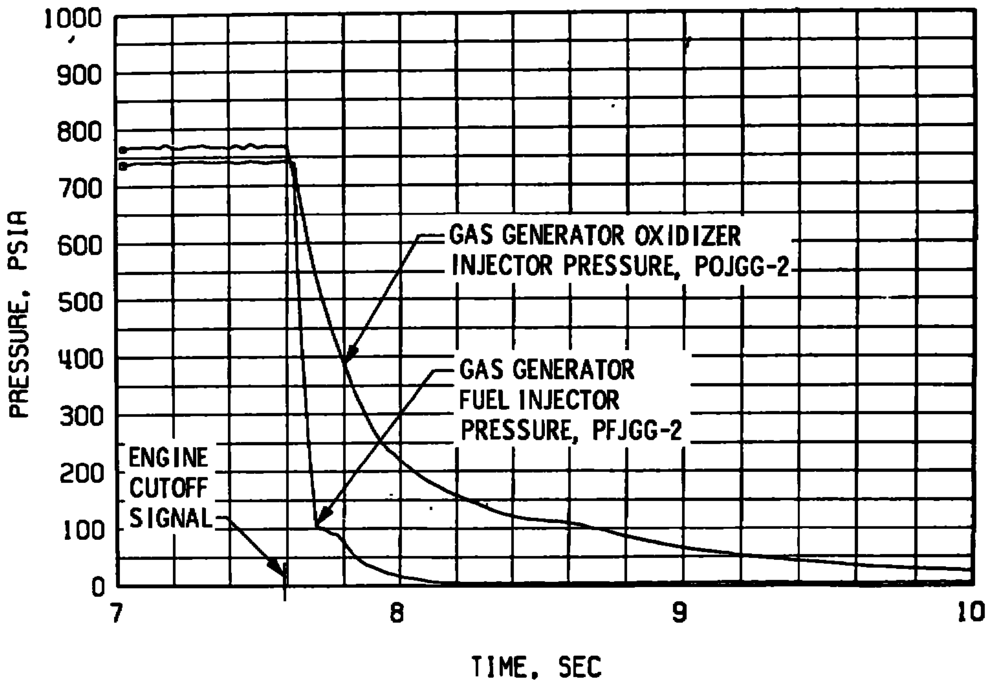


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

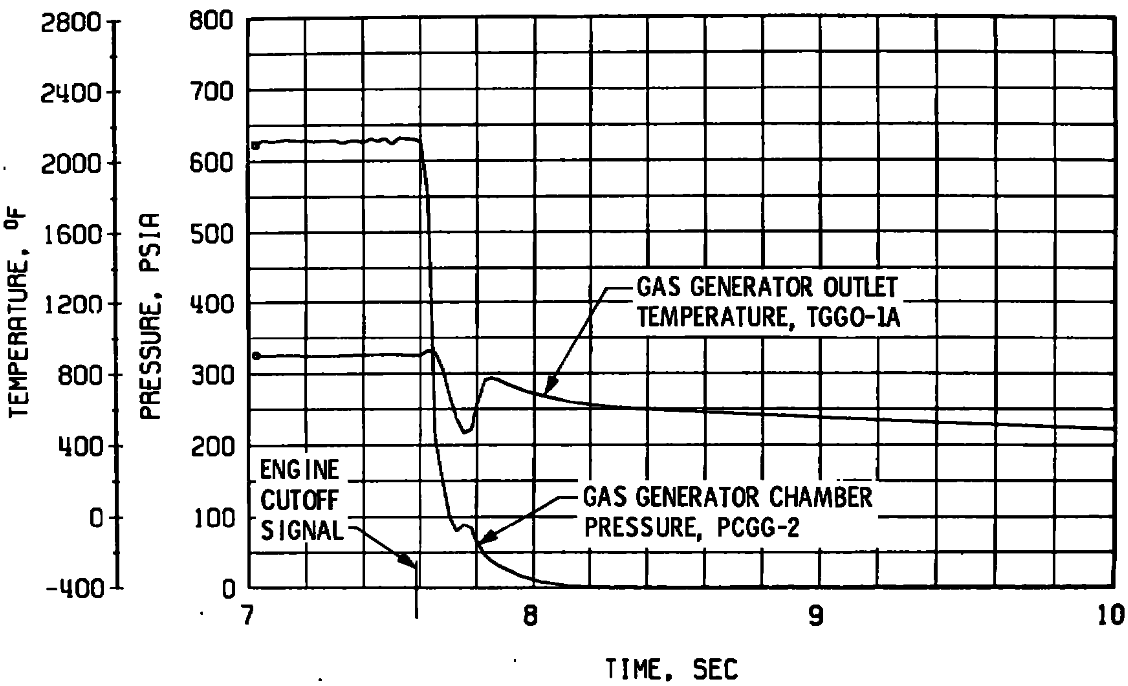


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 19 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown
Fig. 19 Concluded

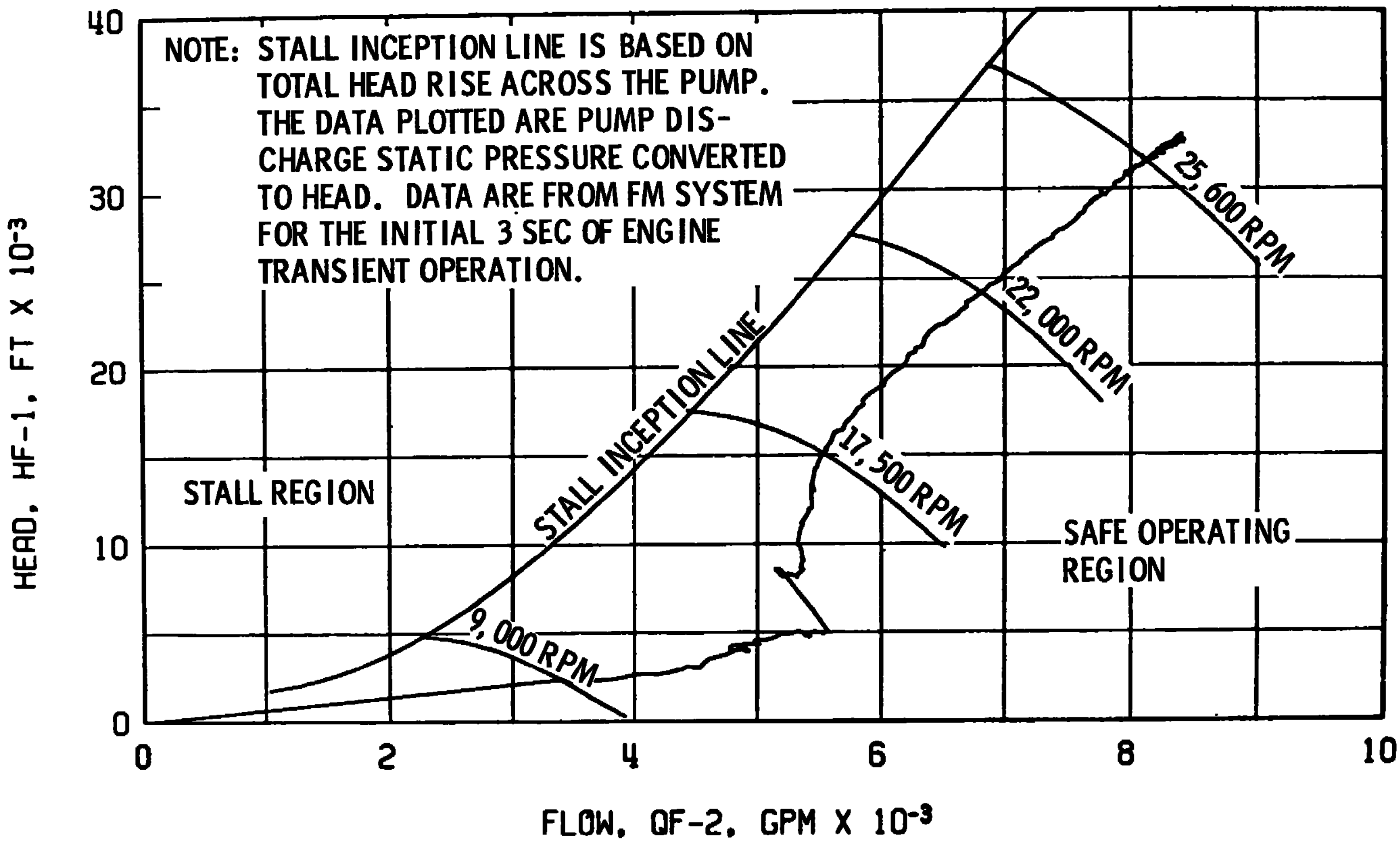
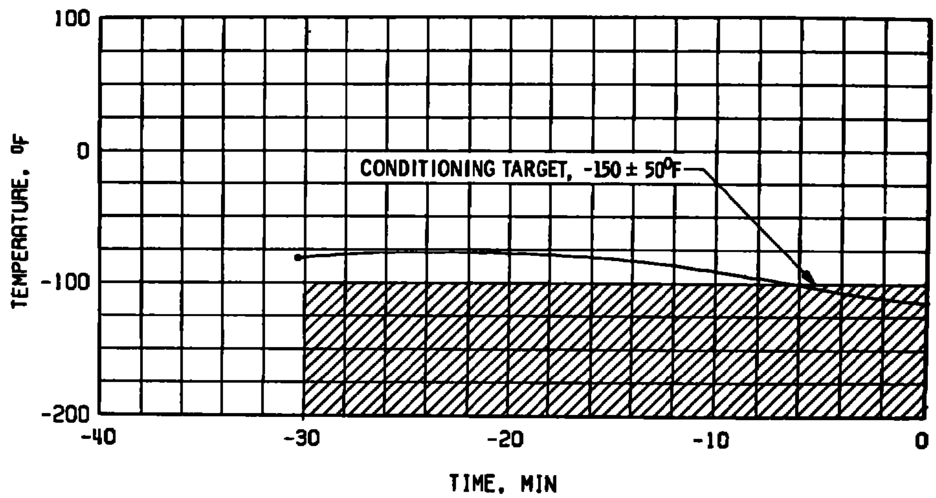
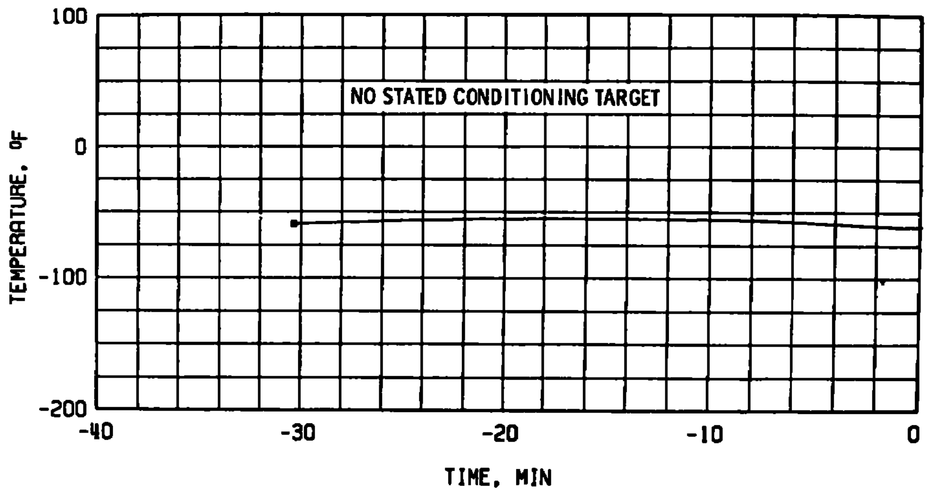


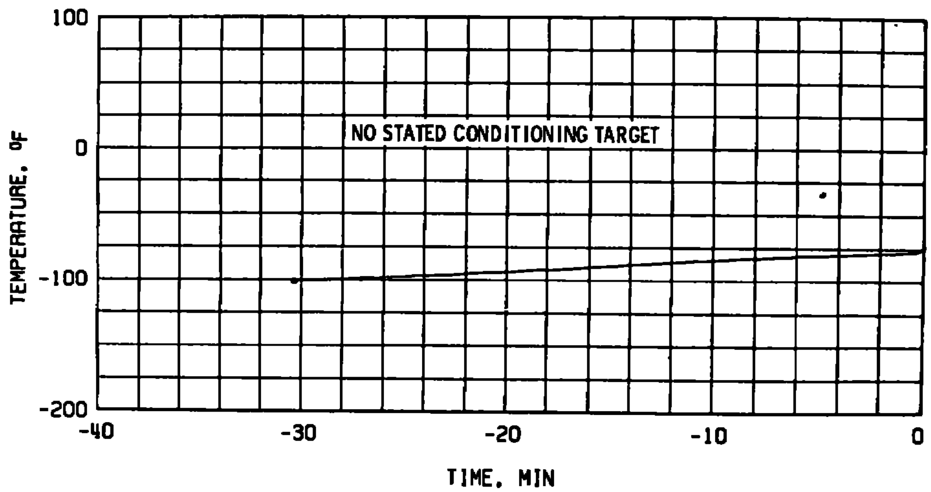
Fig. 20 Fuel Pump Start Transient Performance, Firing 12C



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

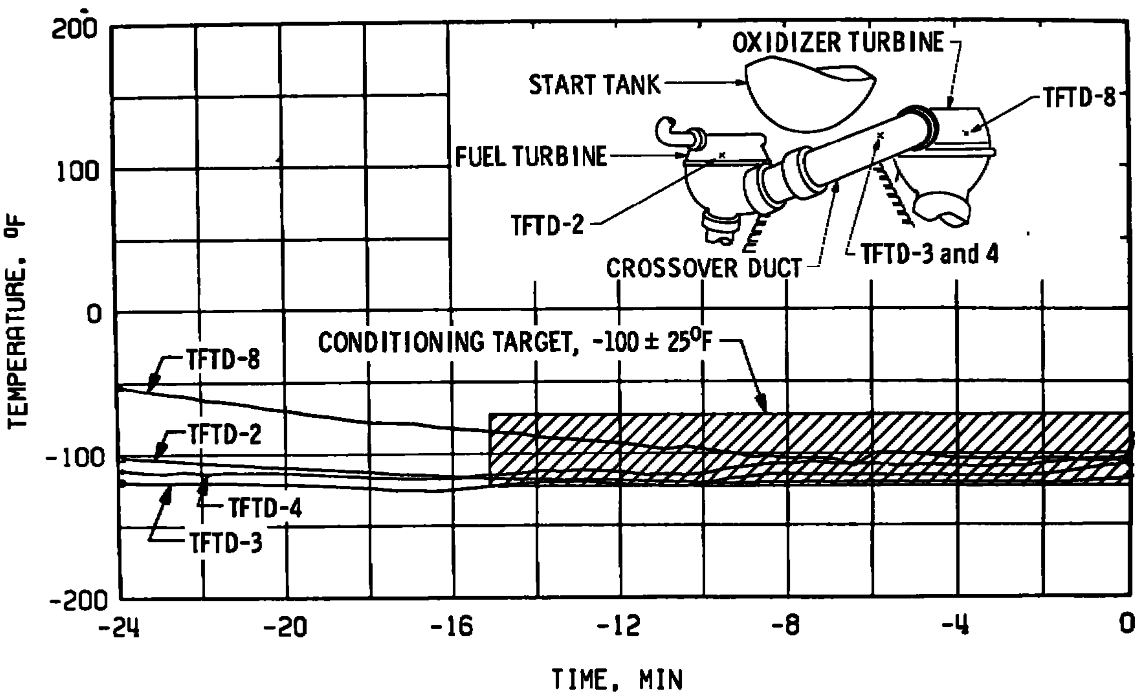


b. Gas Generator Body Temperature, TGGVRS

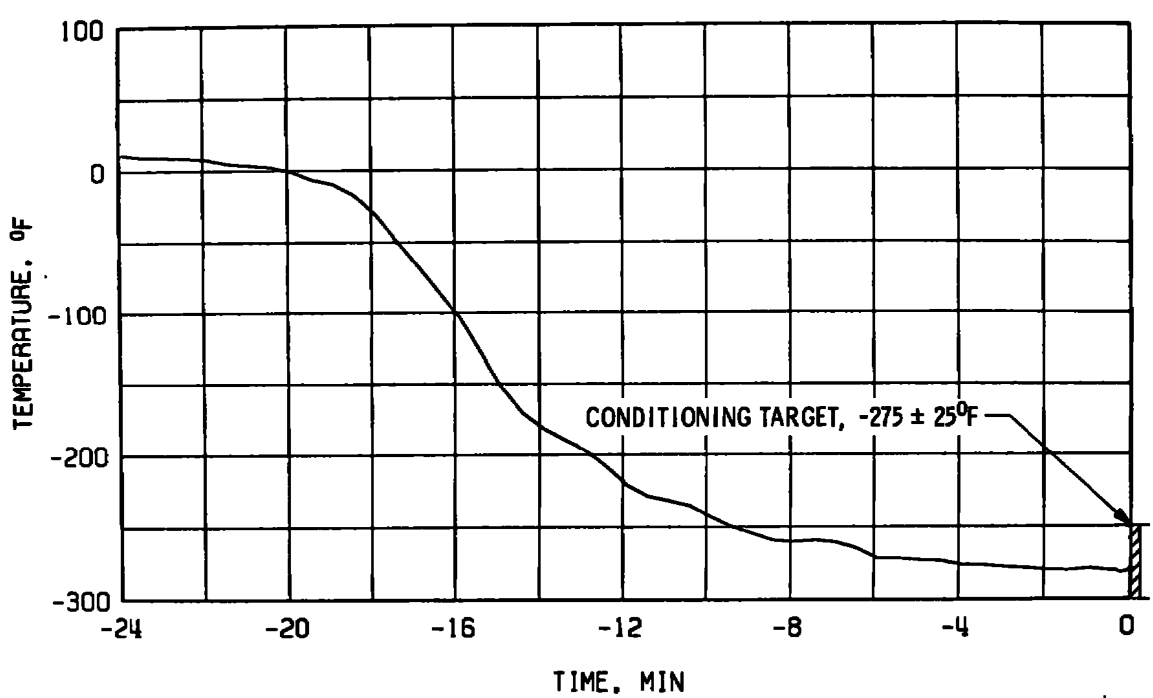


c. Start Tank Discharge Valve Opening Control Temperature, TSTDVOC

Fig. 21 Thermal Conditioning History of Engine Components, Firing 12D



d. Crossover Duct, TFTD



e. Thrust Chamber Throat, TTC-1P

Fig. 21 Concluded

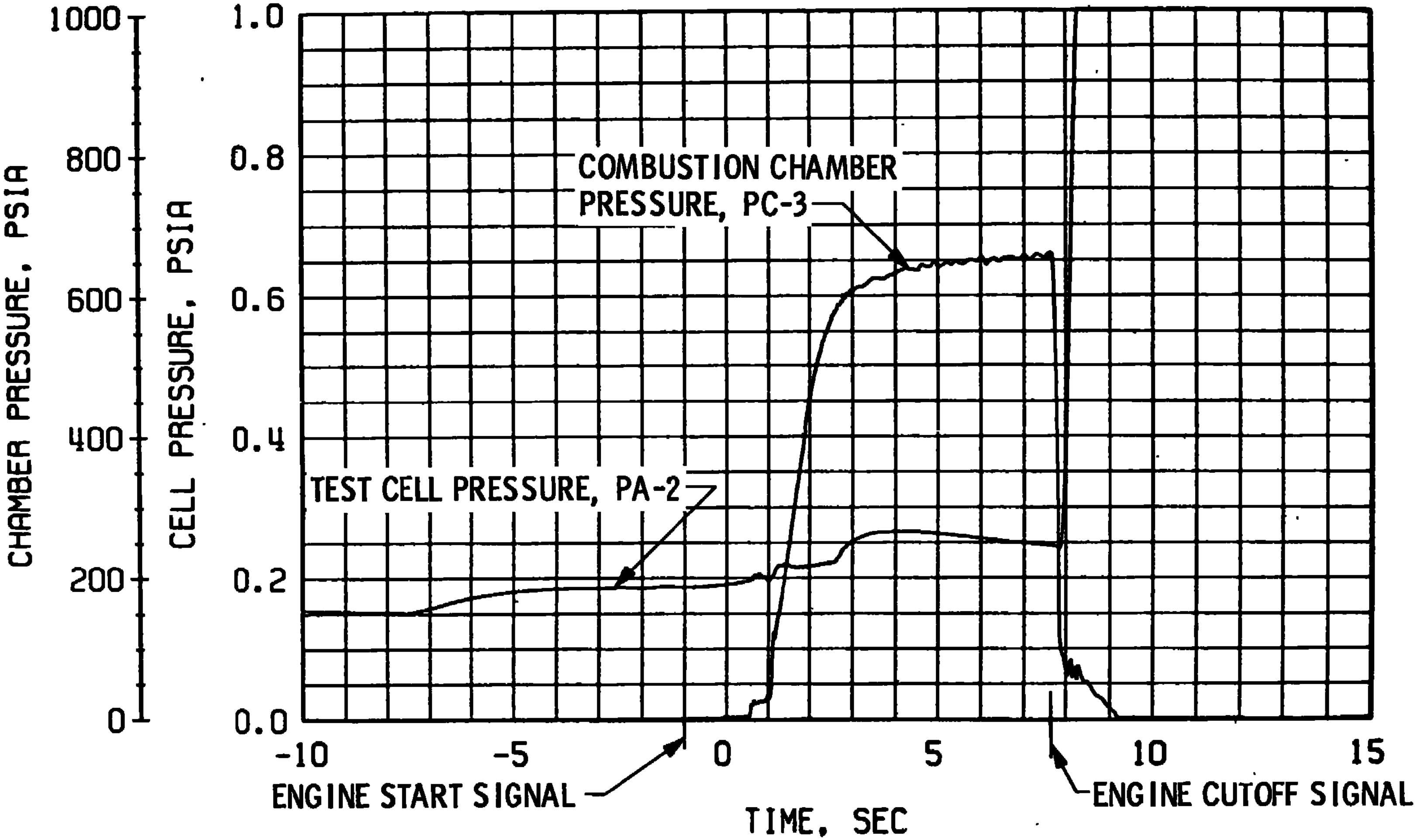
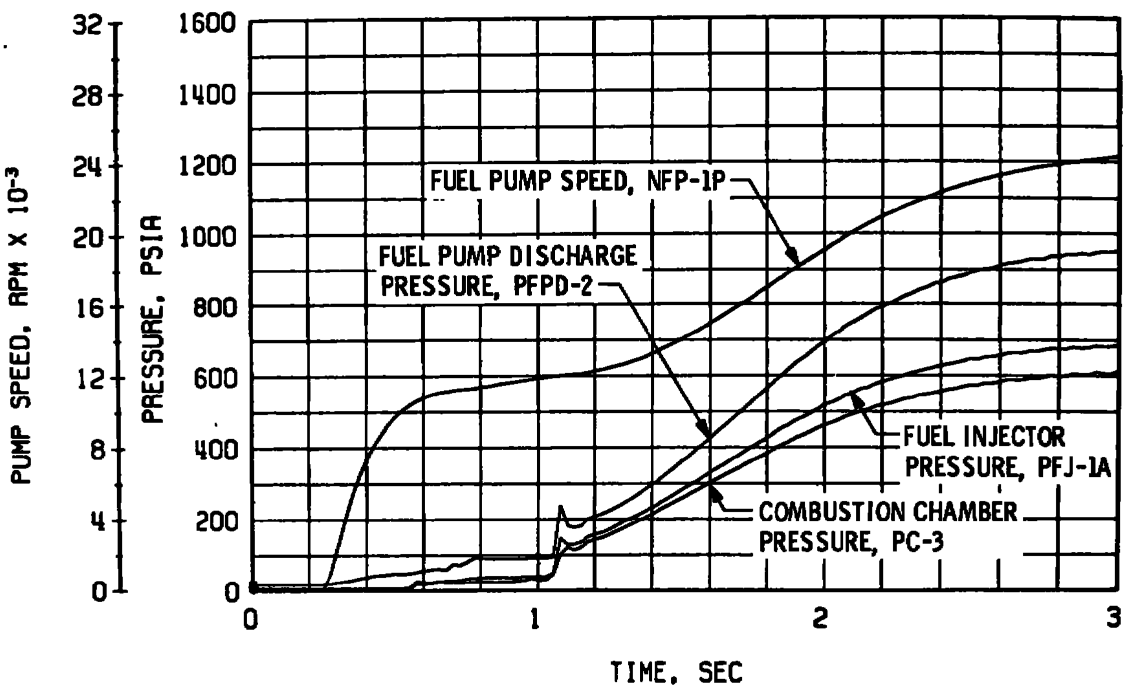
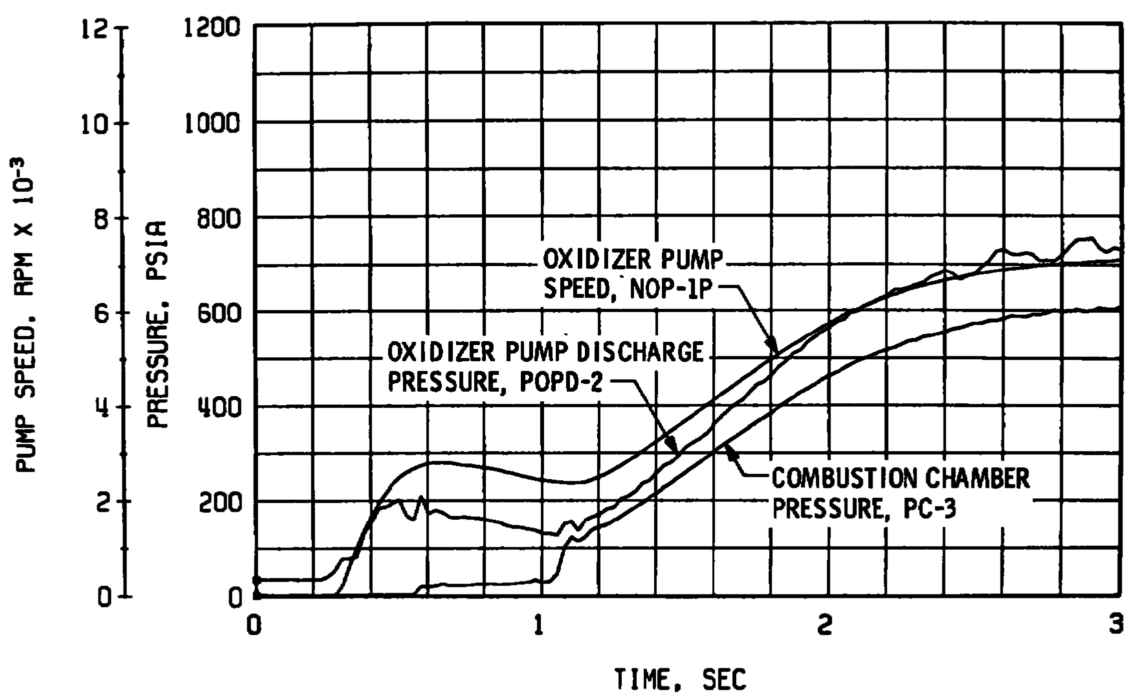


Fig. 22 Engine Ambient and Combustion Chamber Pressures, Firing 12D

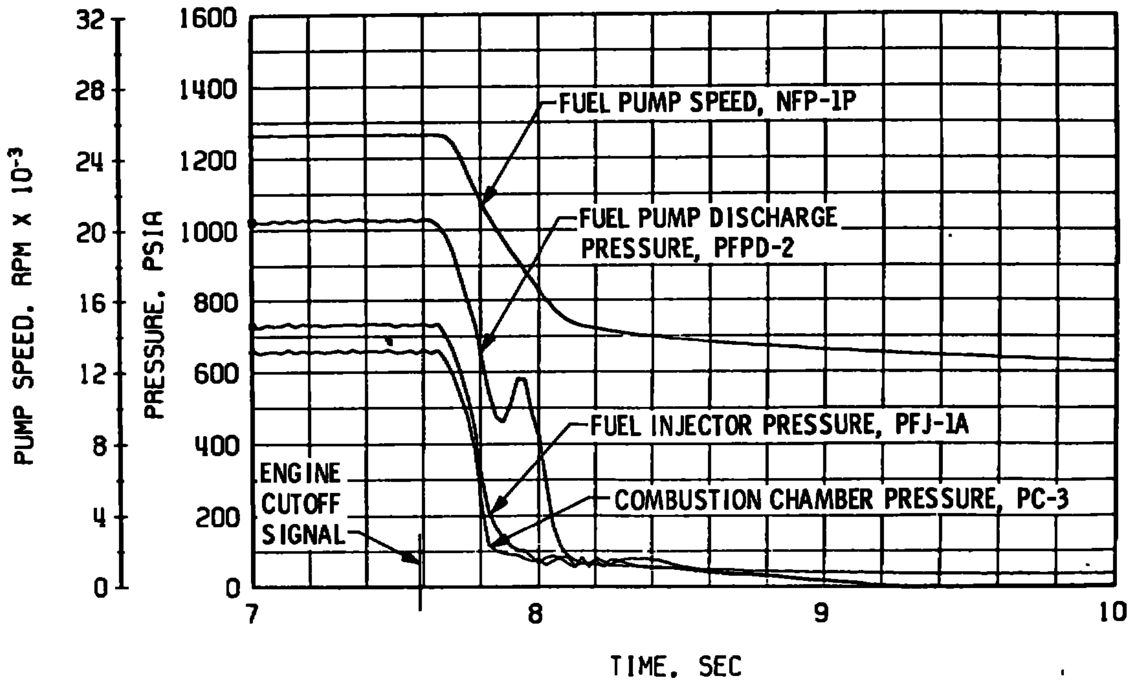


a. Thrust Chamber Fuel System, Start

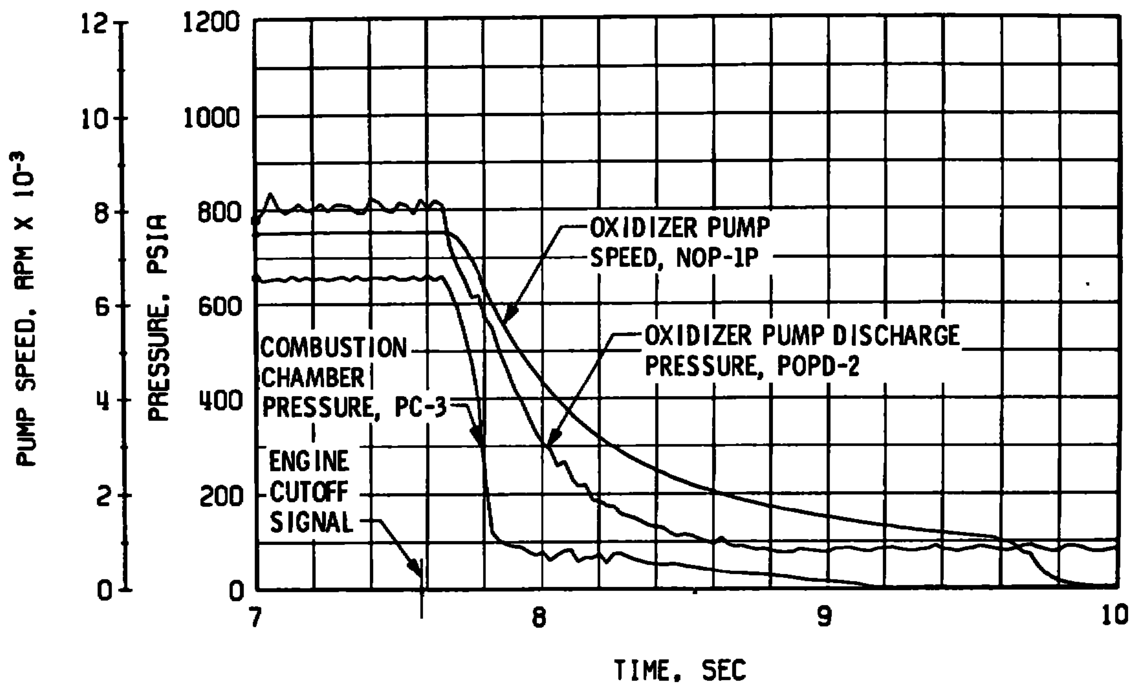


b. Thrust Chamber Oxidizer System, Start

Fig. 23 Engine Transient Operation, Firing 12D

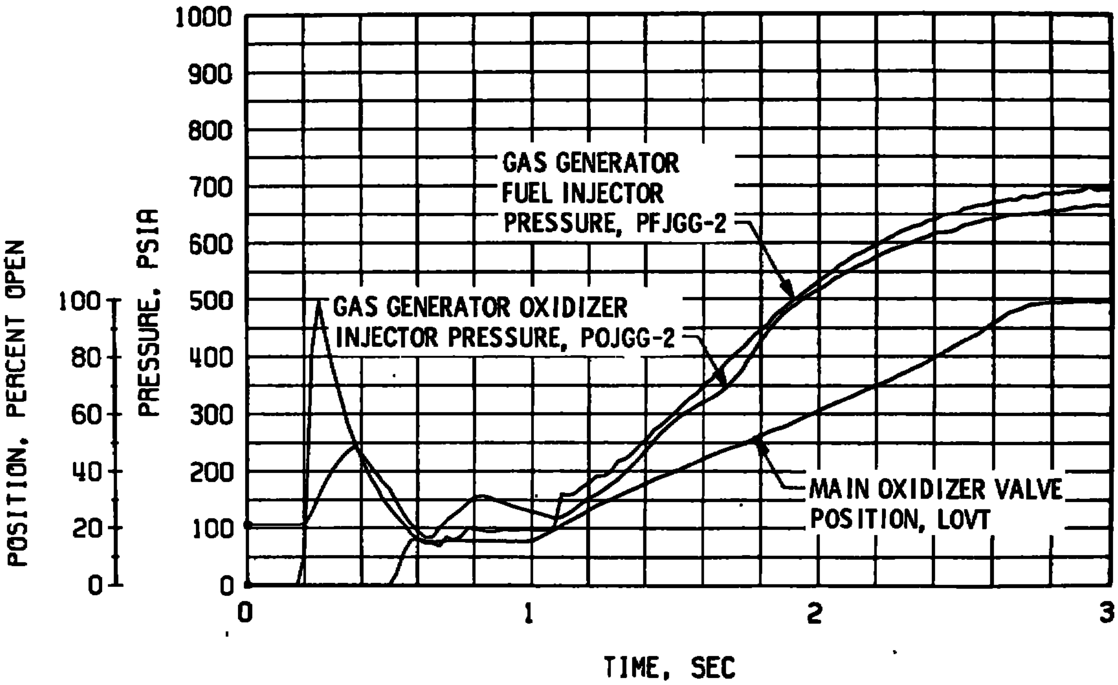


c. Thrust Chamber Fuel System, Shutdown

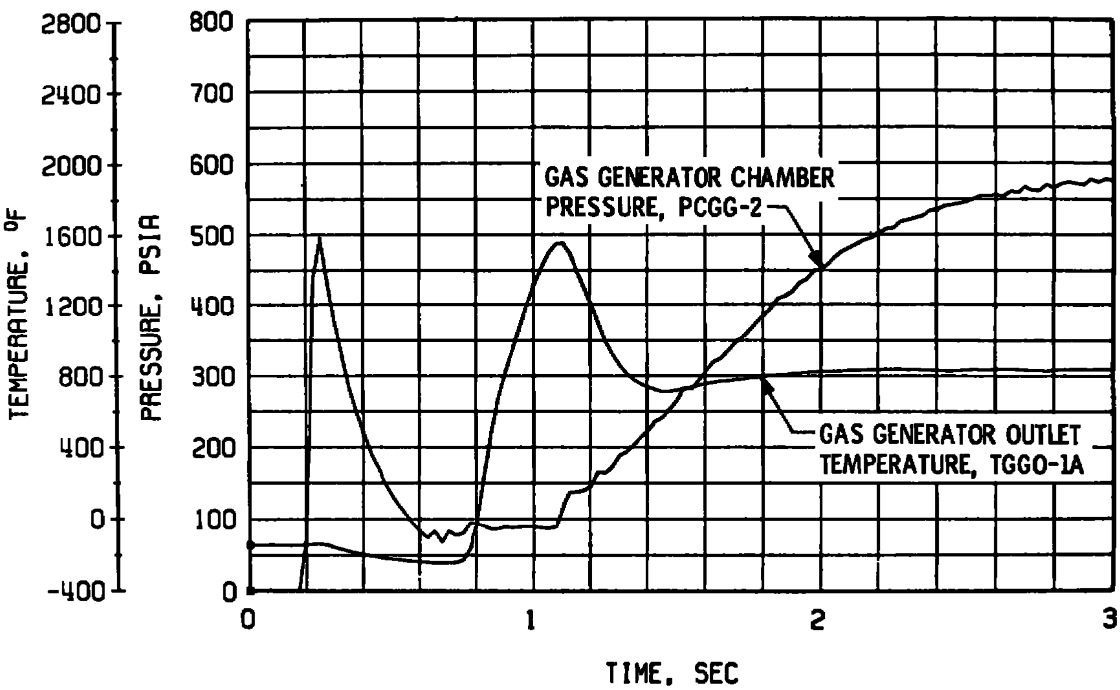


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 23 Continued

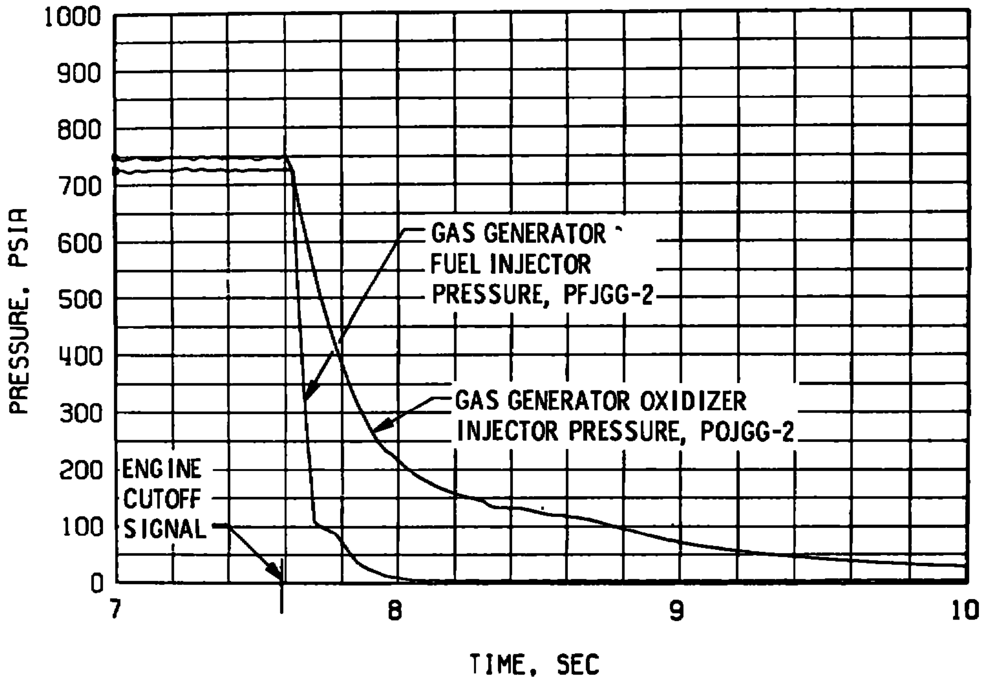


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

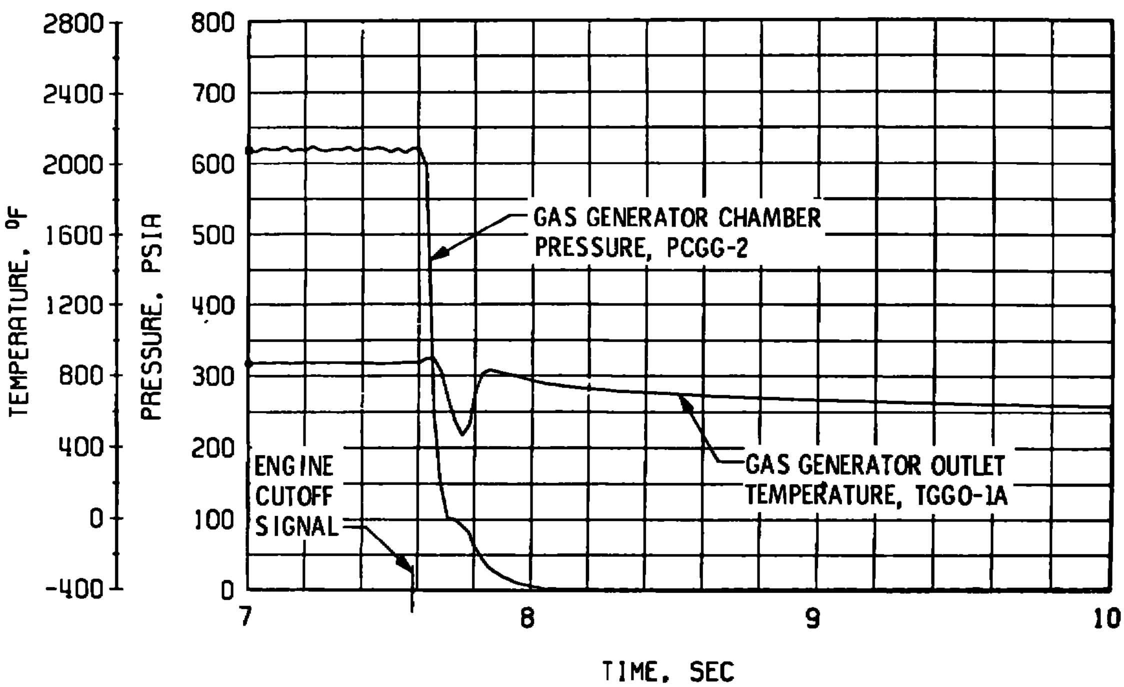


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 23 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 23 Concluded

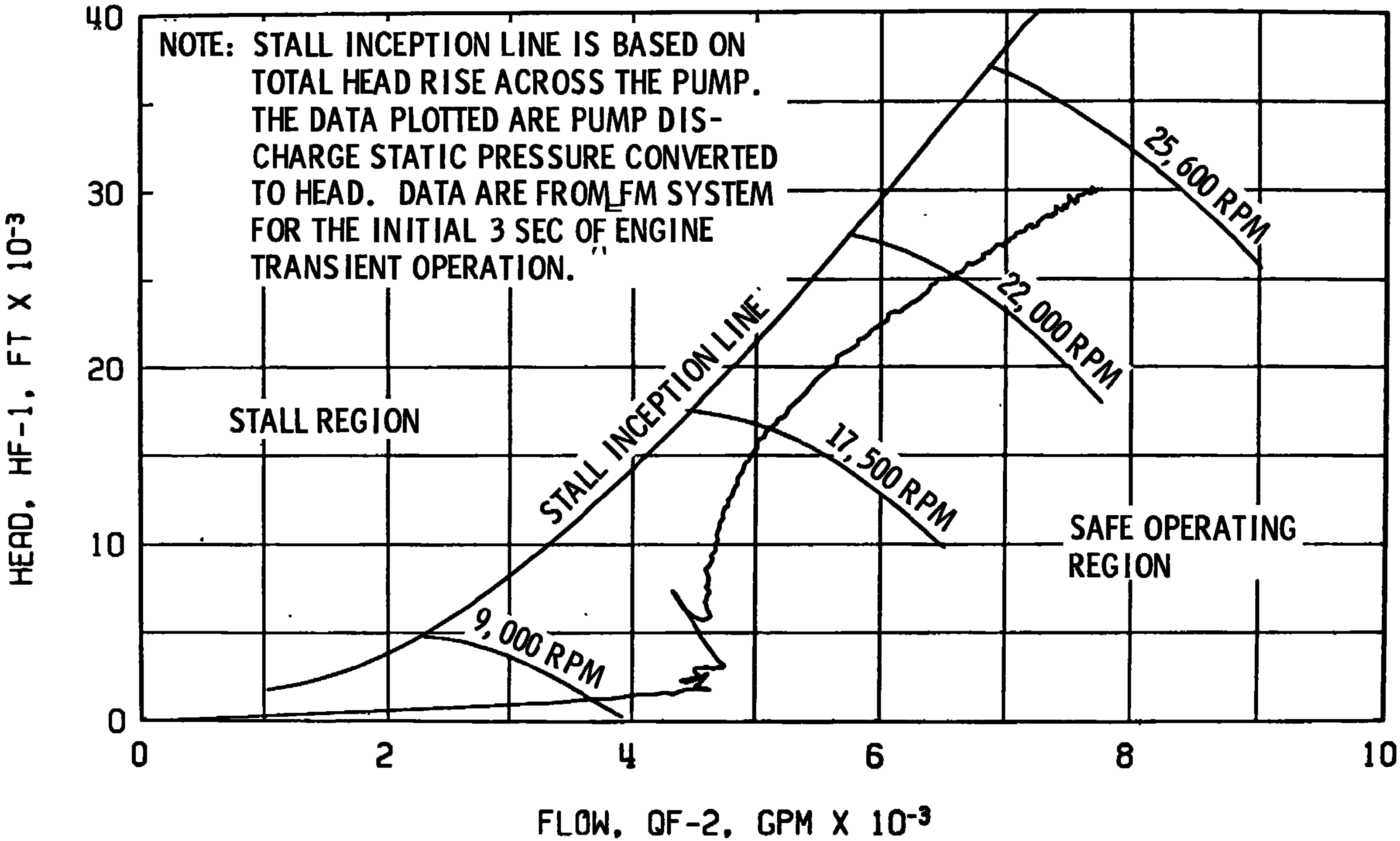
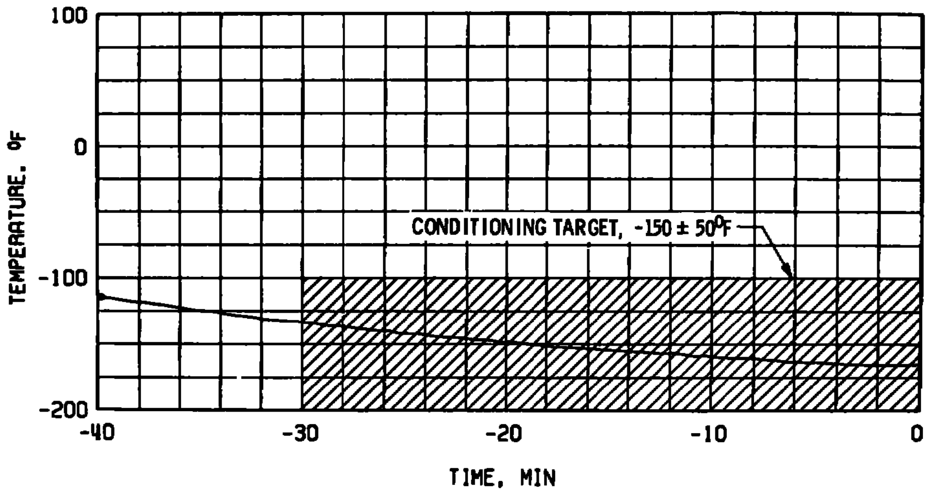
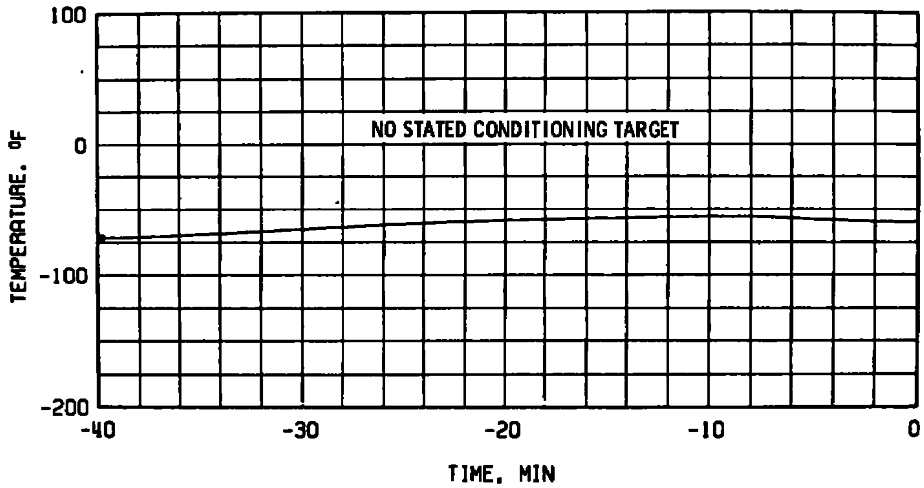


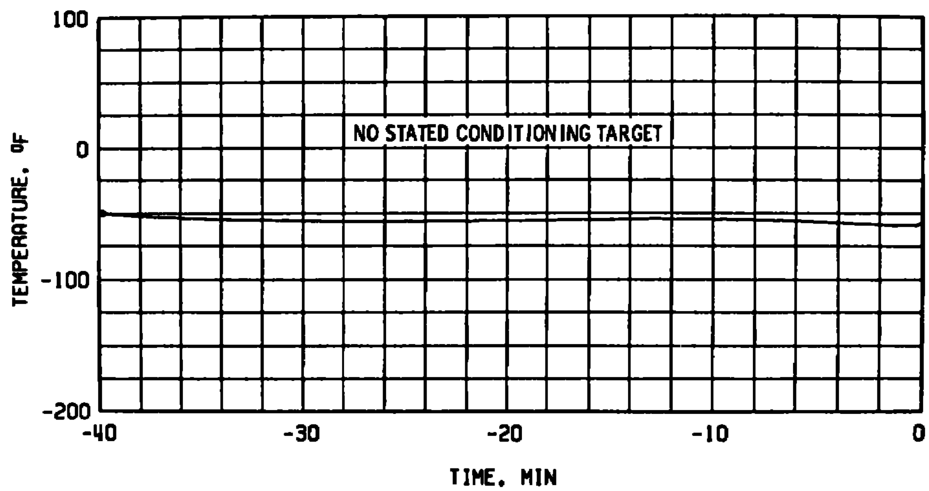
Fig. 24 Fuel Pump Start Transient Performance, Firing 12D



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

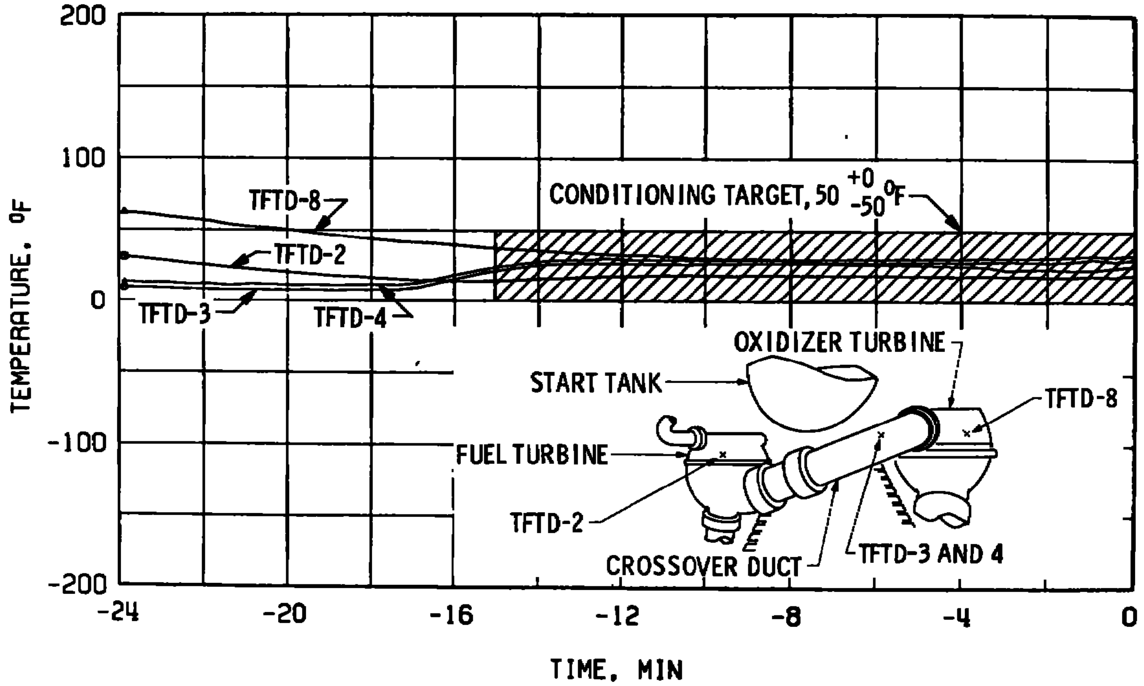


b. Gas Generator Body Temperature, TGGVRS

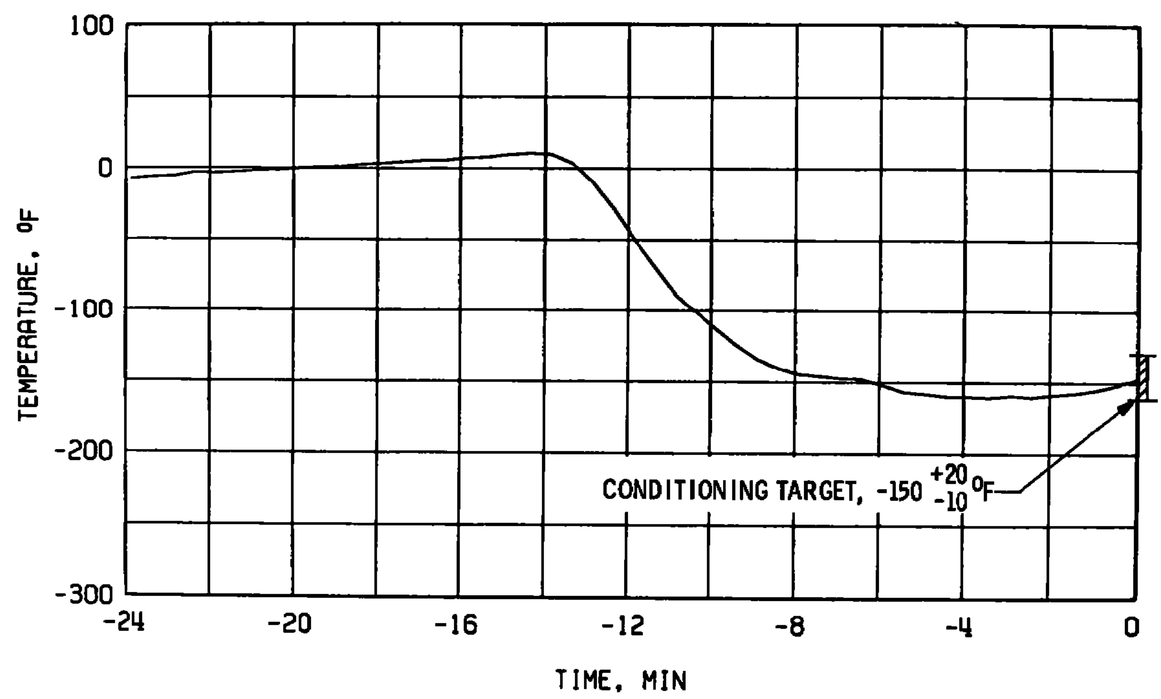


c. Start Tank Discharge Valve Opening Control Temperature, TSTDVOC

Fig. 25 Thermal Conditioning History of Engine Components, Firing 12E



d. Crossover Duct, TFTD



e. Thrust Chamber Throat, TTC-1P
Fig. 25 Concluded

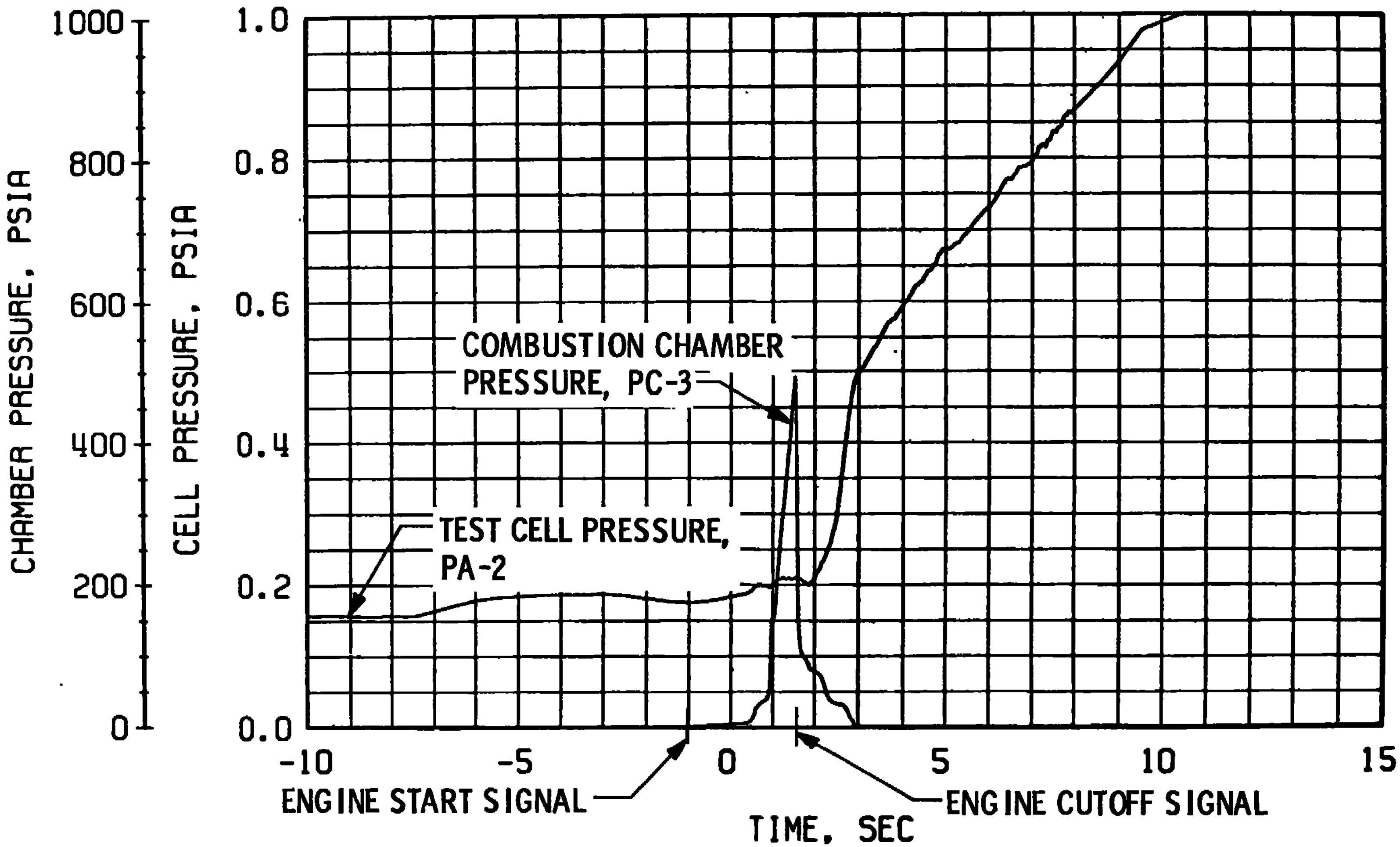
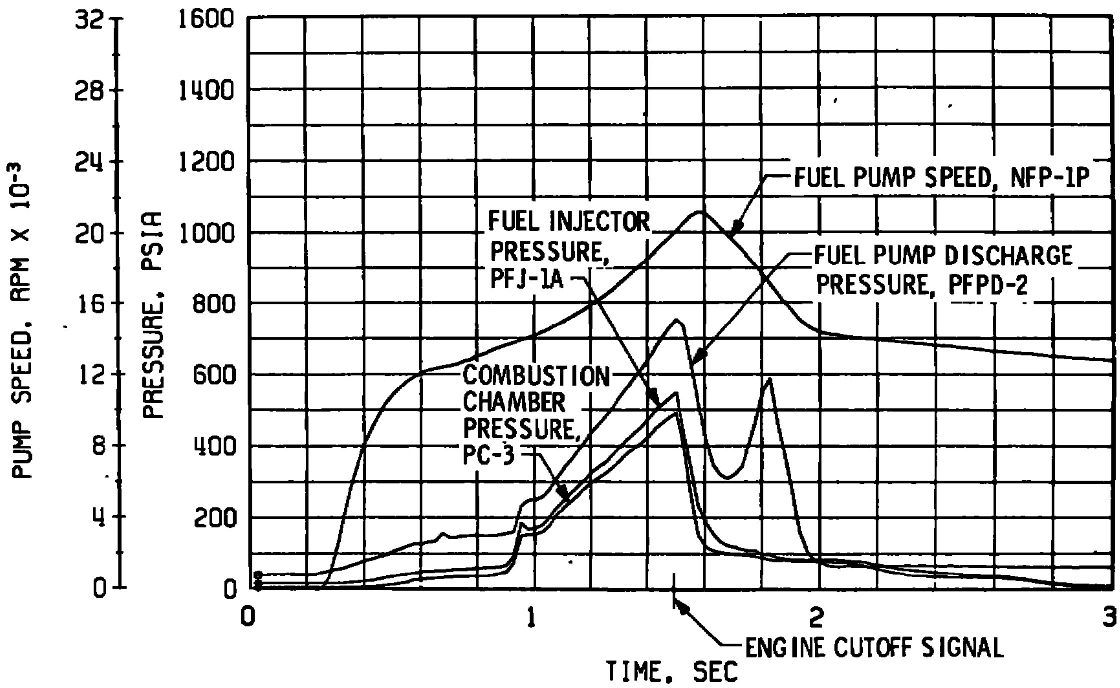
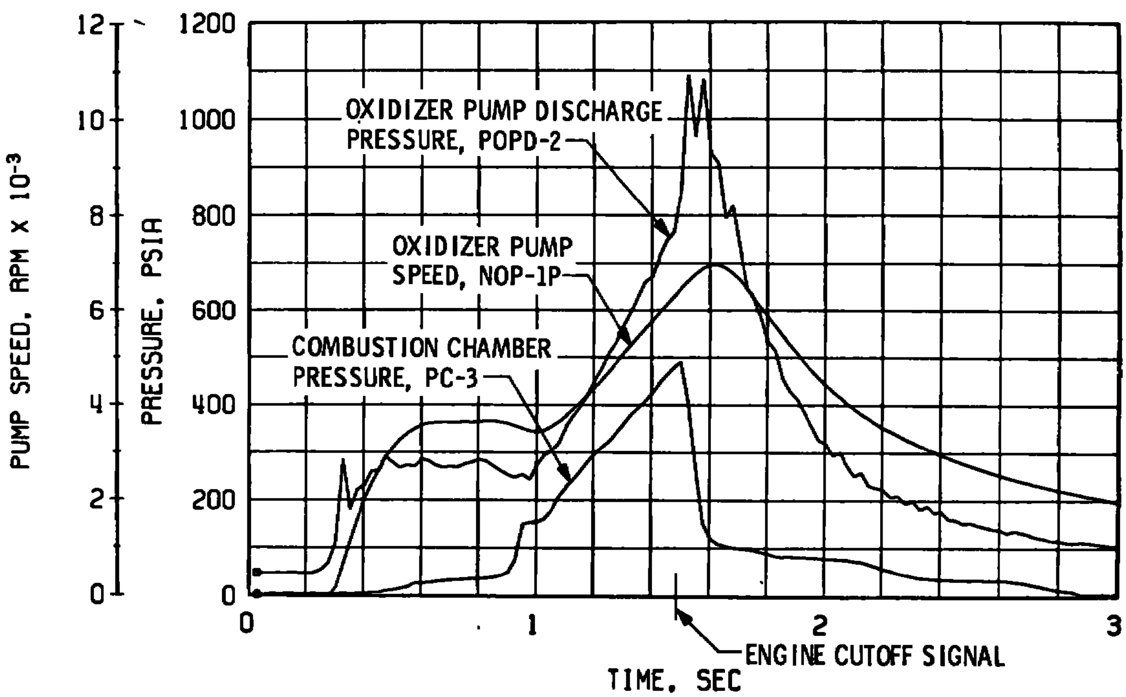


Fig. 26 Engine Ambient and Combustion Chamber Pressures, Firing 12E

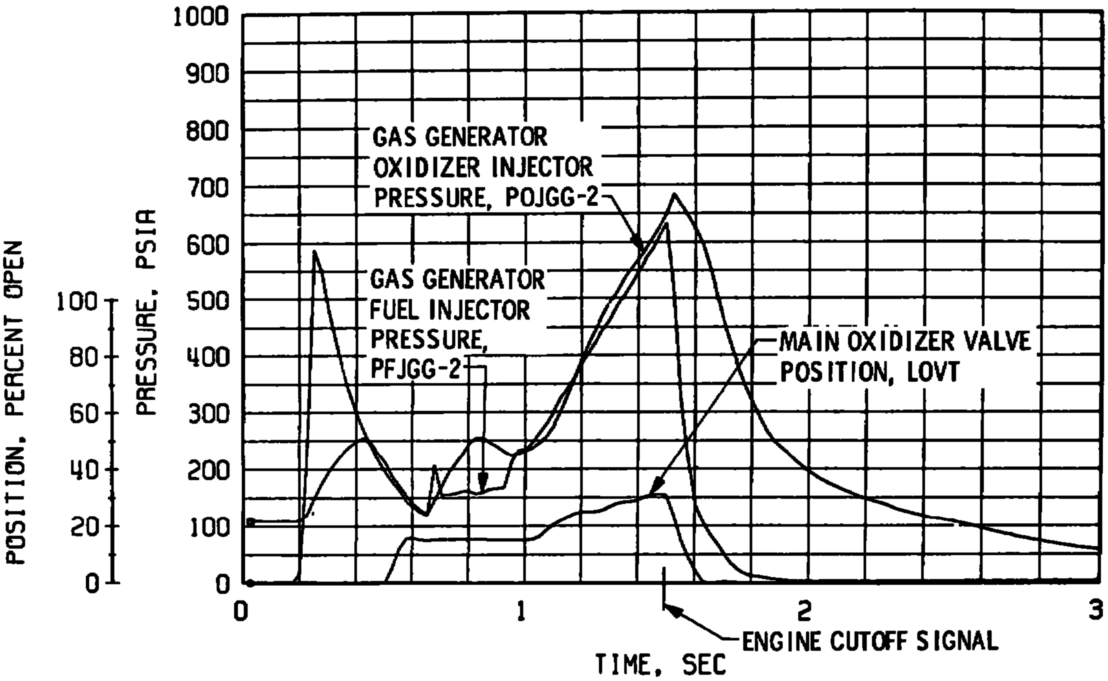


a. Thrust Chamber Fuel System, Start and Shutdown

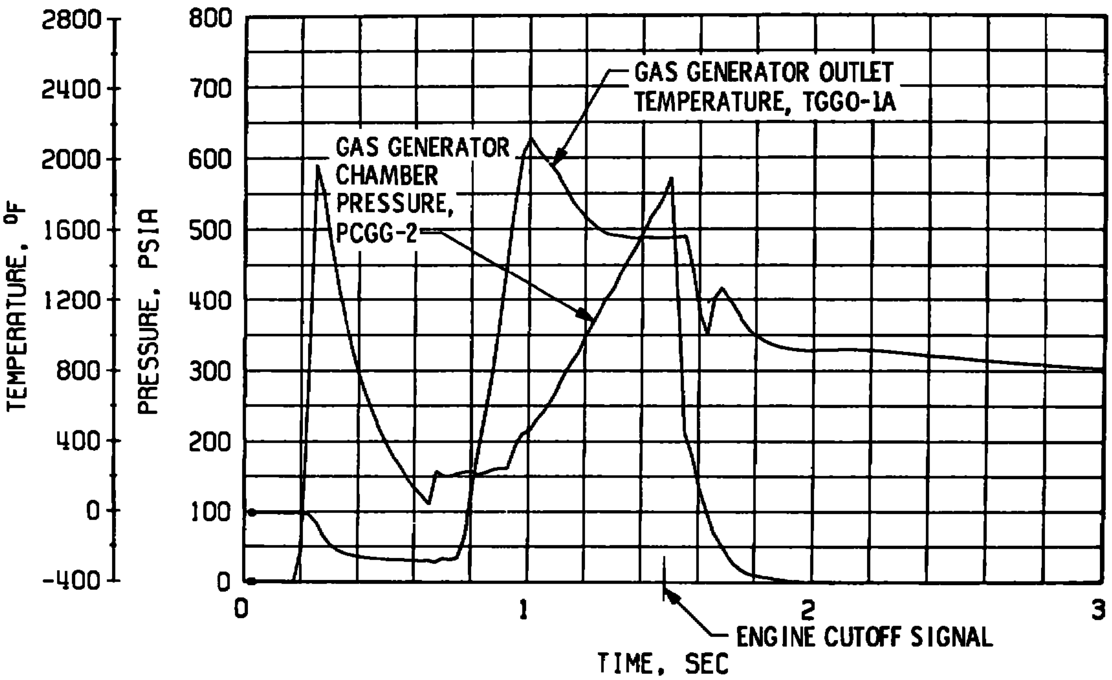


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 27 Engine Transient Operation, Firing 12E



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 27 Concluded

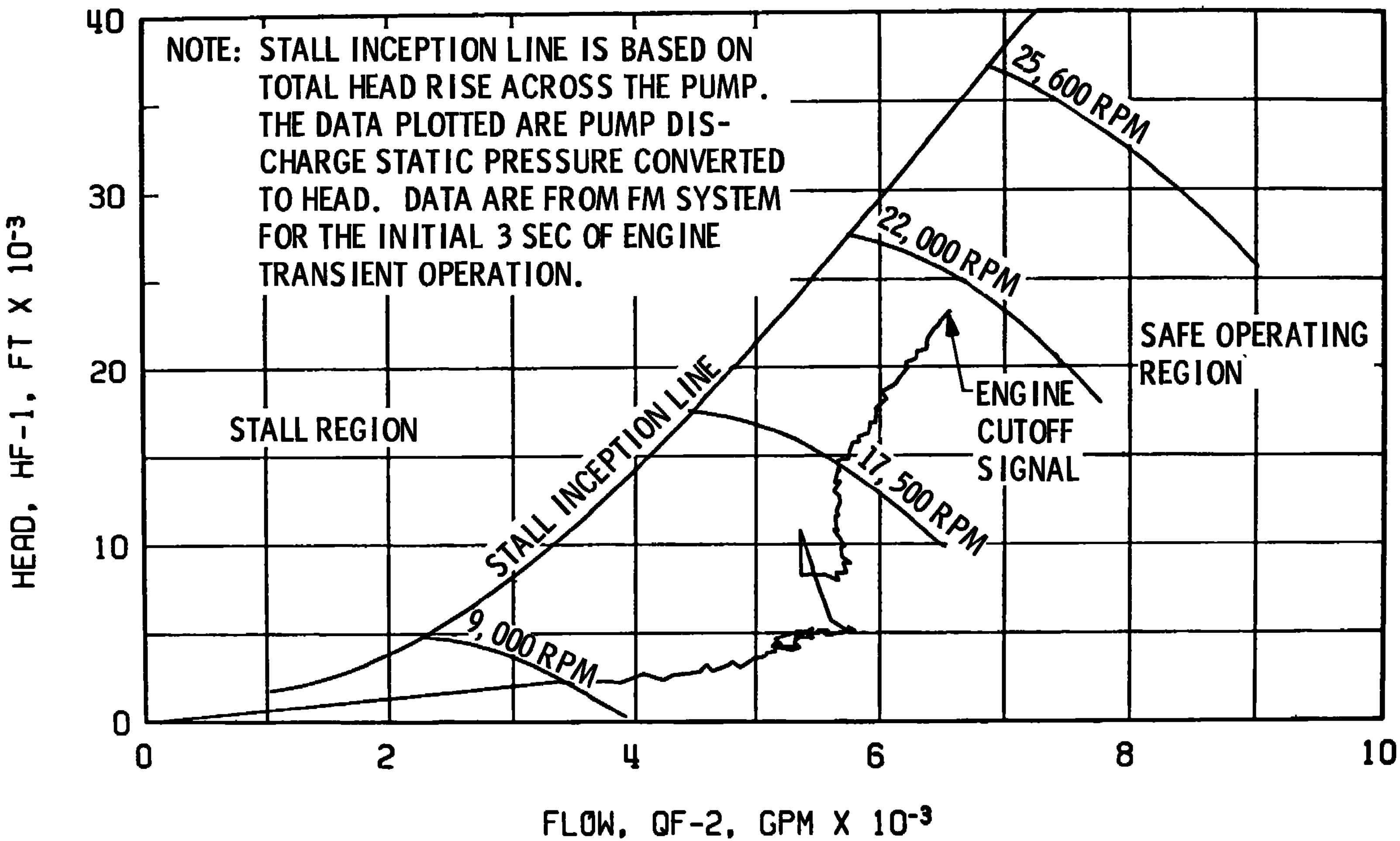
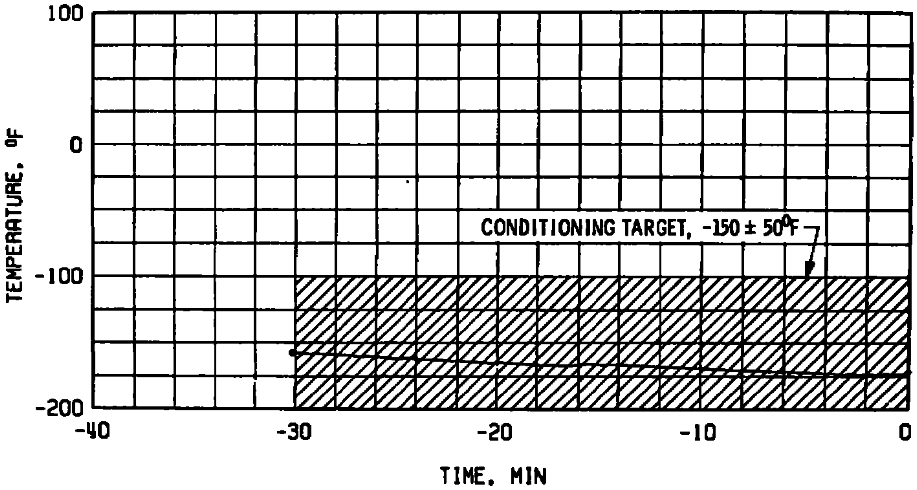
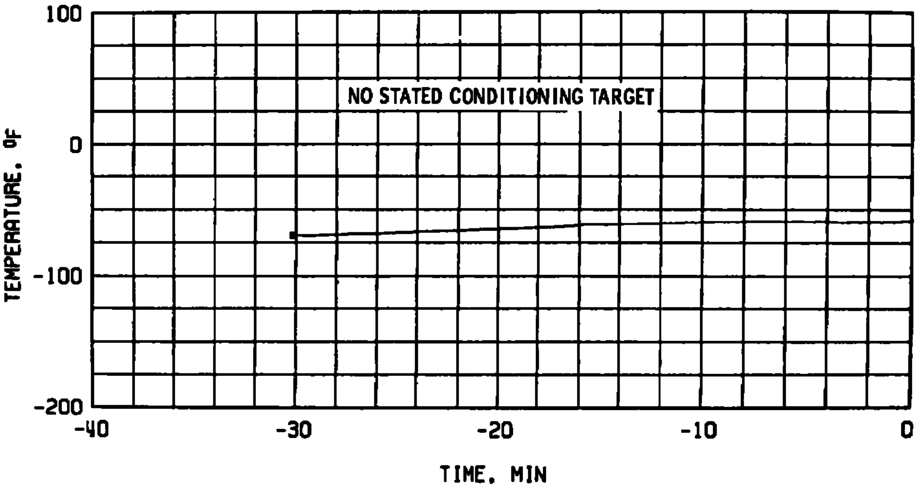


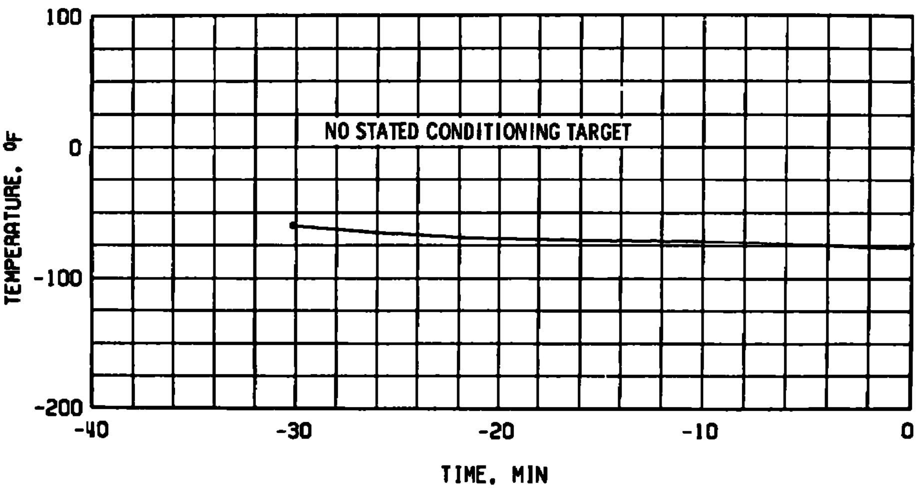
Fig. 28 Fuel Pump Start Transient Performance, Firing 12E



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

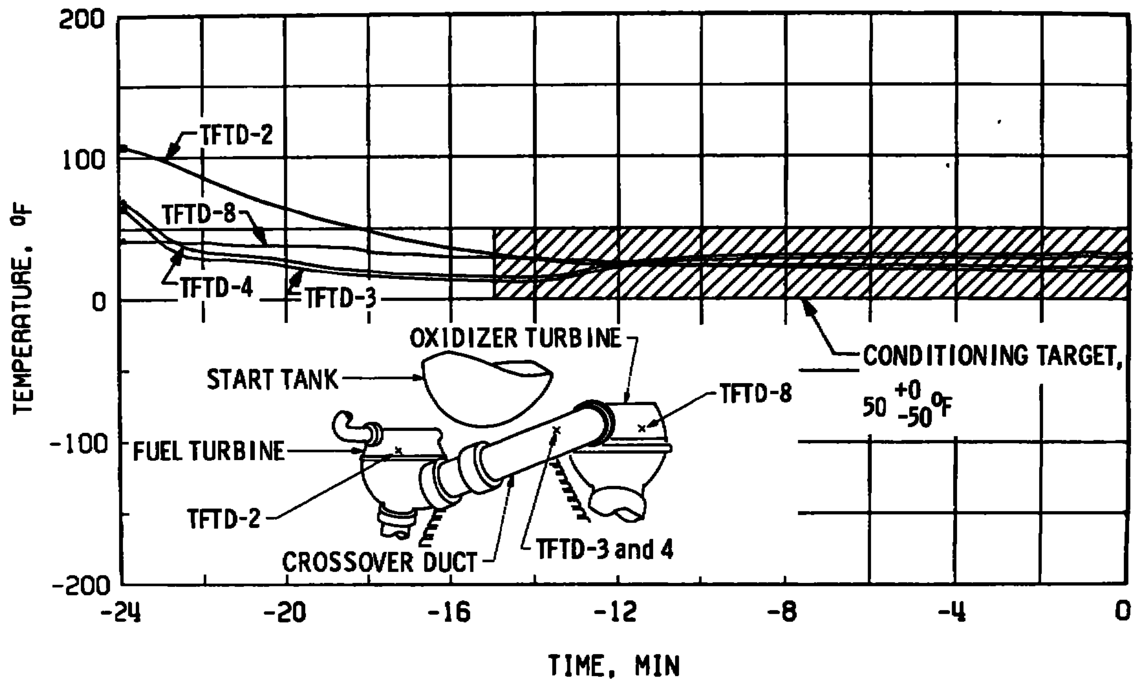


b. Gas Generator Body Temperature, TGGVRS

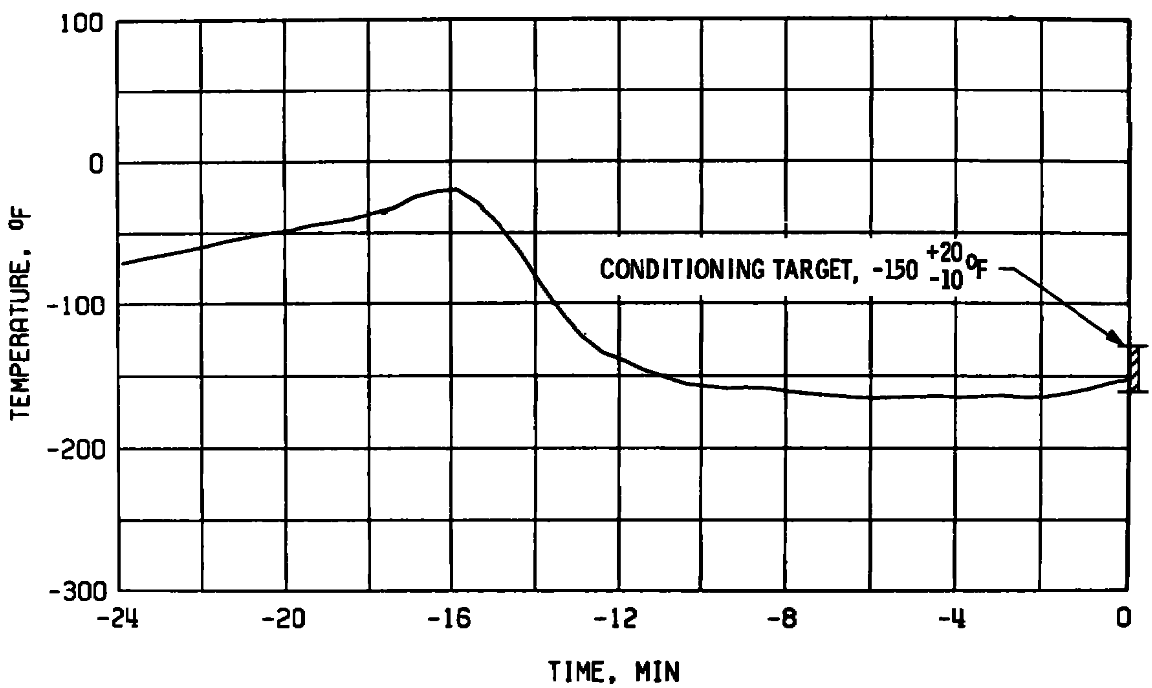


c. Start Tank Discharge Valve Opening Control Temperature, TSTDVOC

Fig. 29 Thermal Conditioning History of Engine Components, Firing 12F.



d. Crossover Duct, TFTD



e. Thrust Chamber Throat, TTC-1P

Fig. 29 Concluded

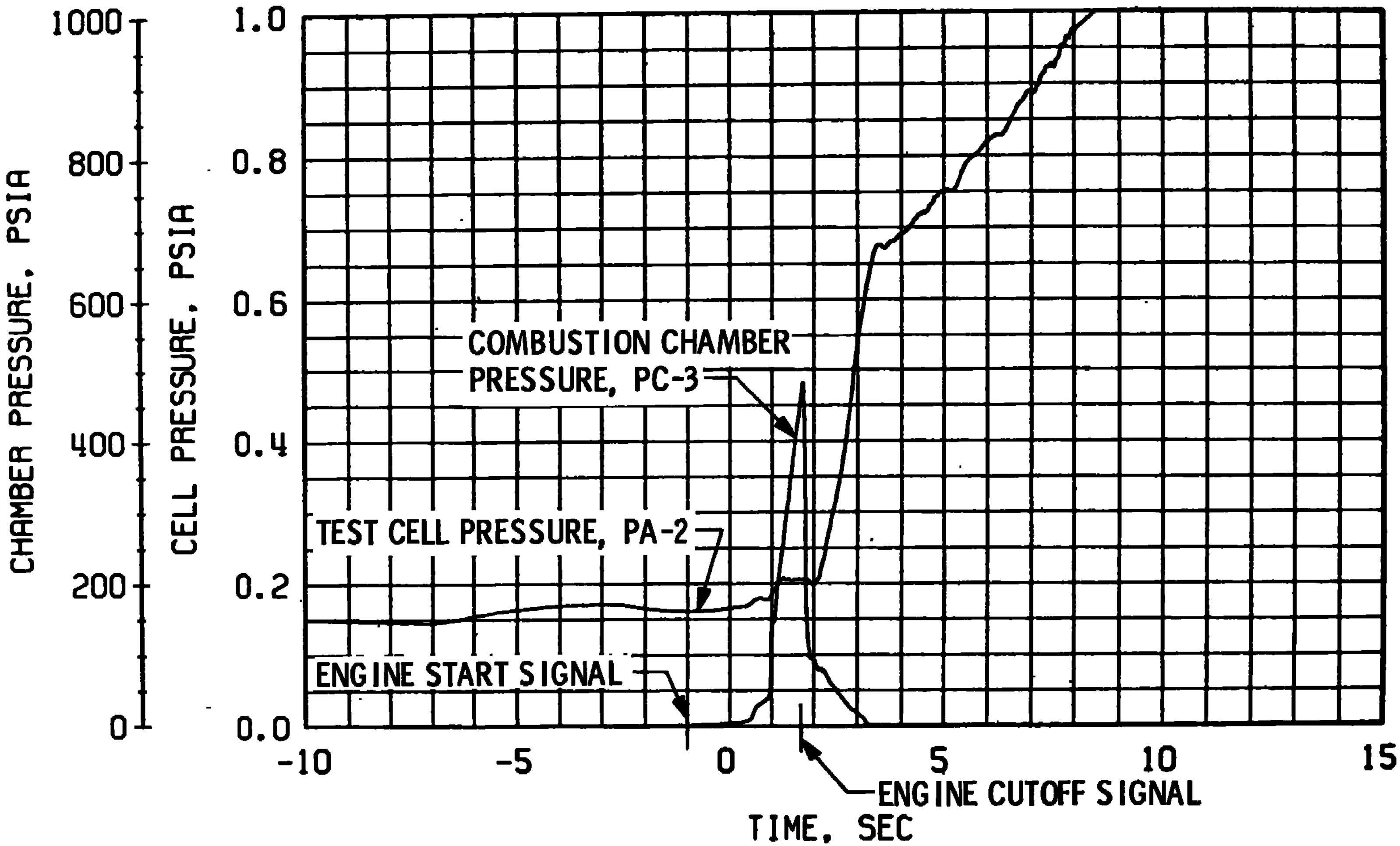
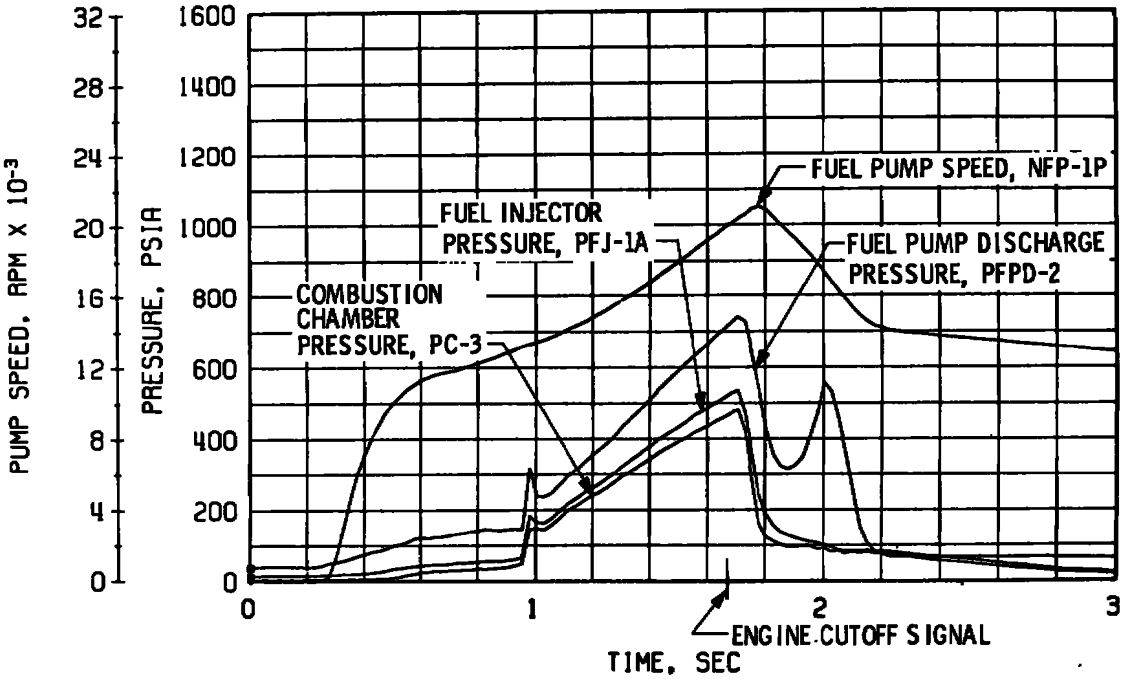
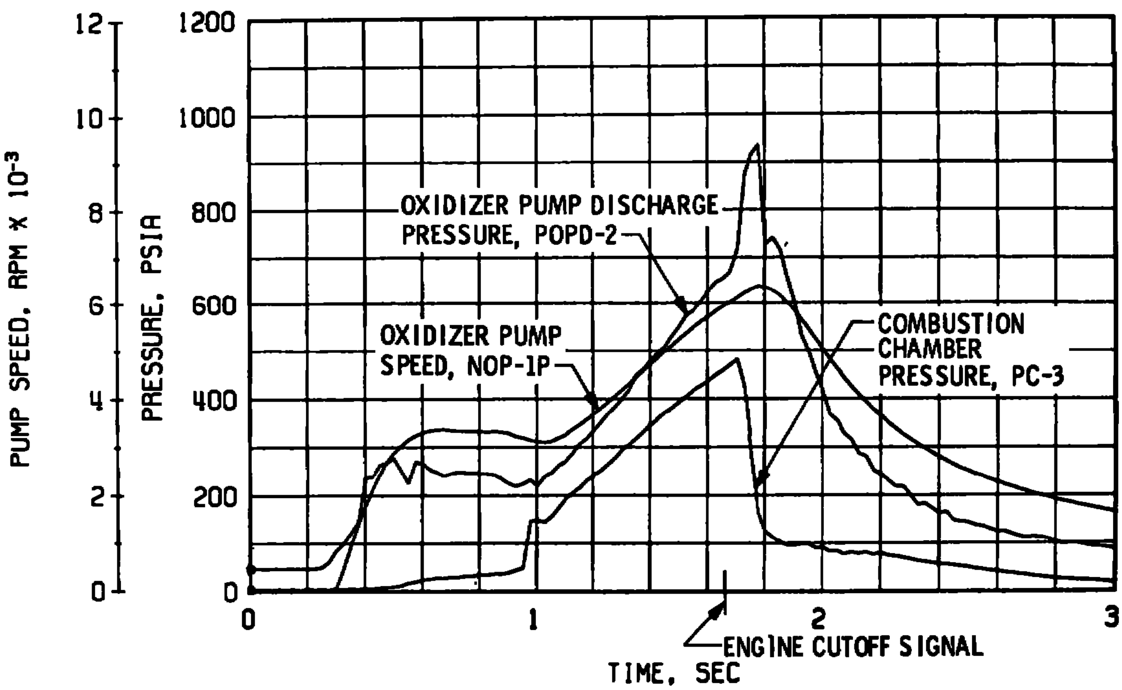


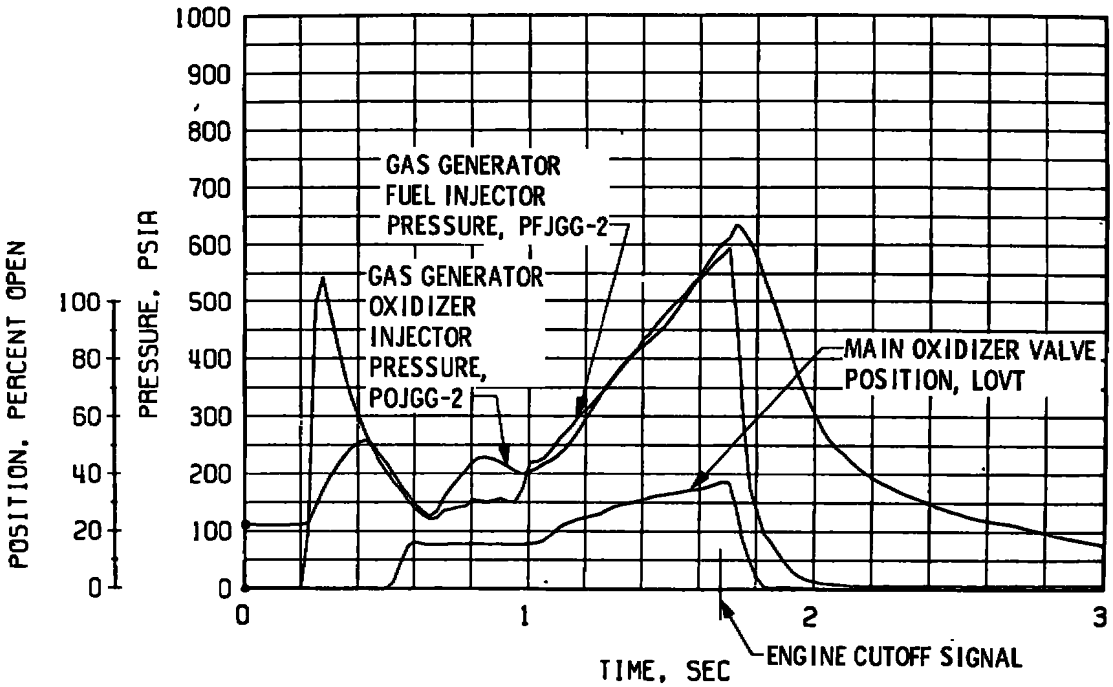
Fig. 30 Engine Ambient and Combustion Chamber Pressures, Firing 12F



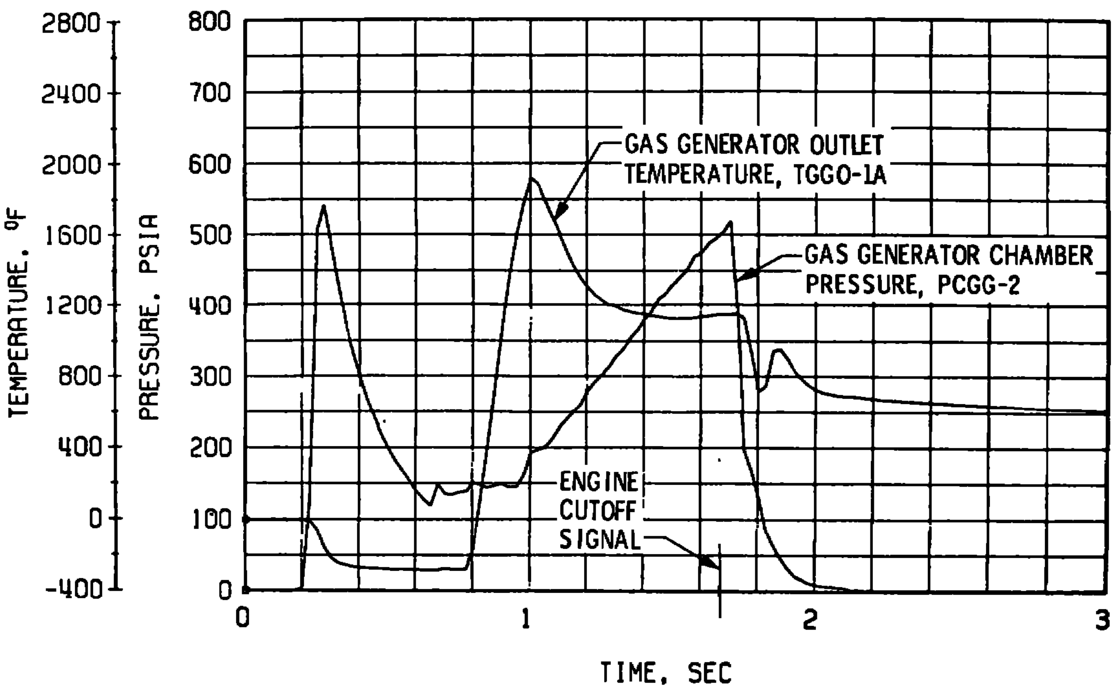
a. Thrust Chamber Fuel System, Start and Shutdown



b. Thrust Chamber Oxidizer System, Start and Shutdown
Fig. 31 Engine Transient Operation, Firing 12F



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 31 Concluded

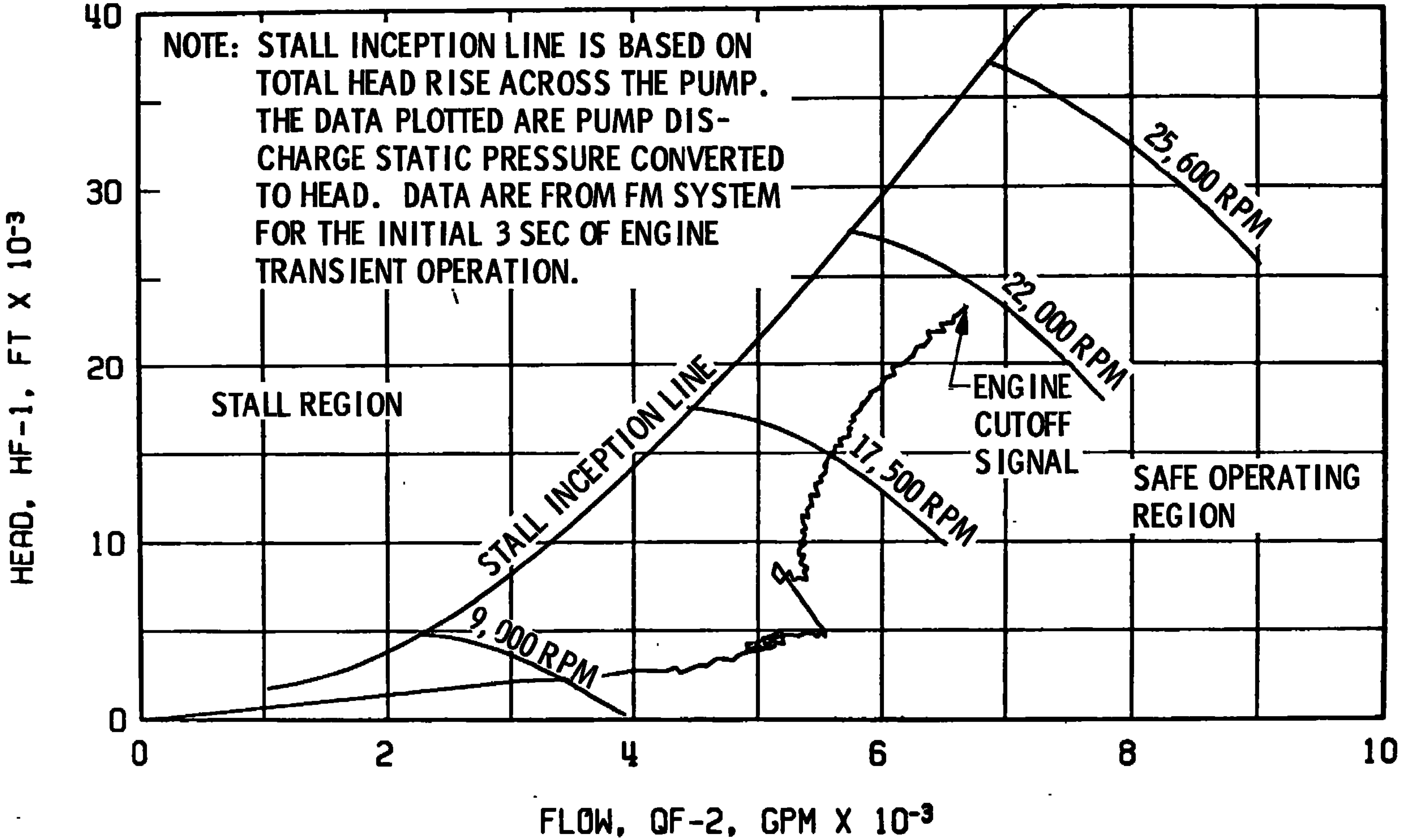
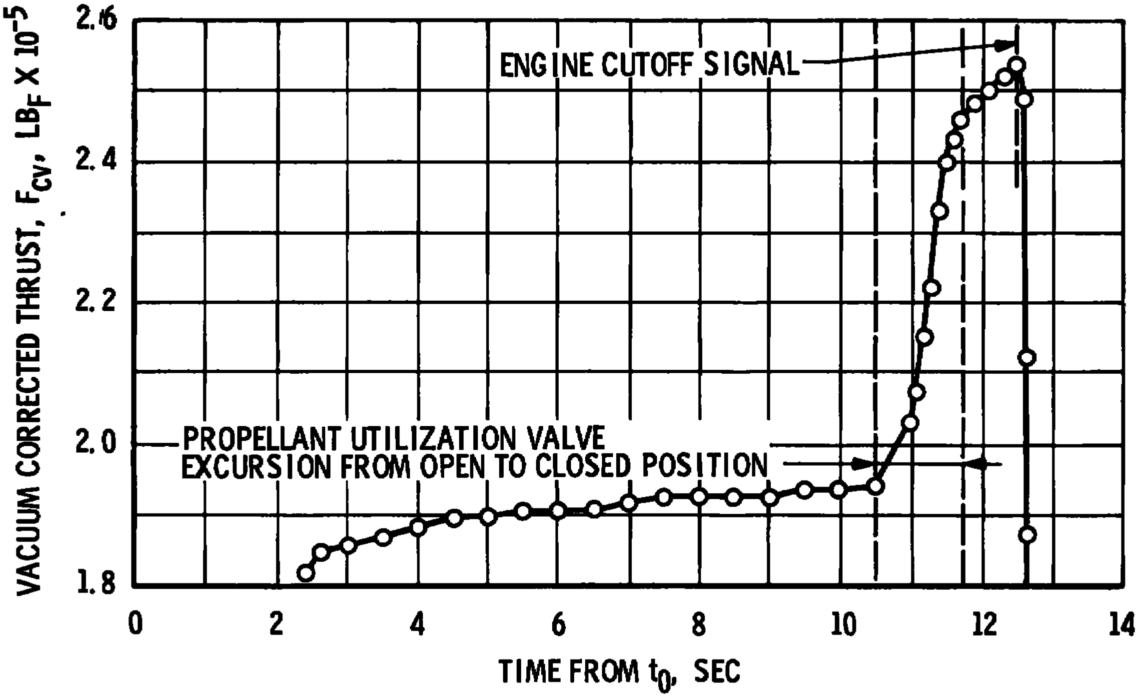
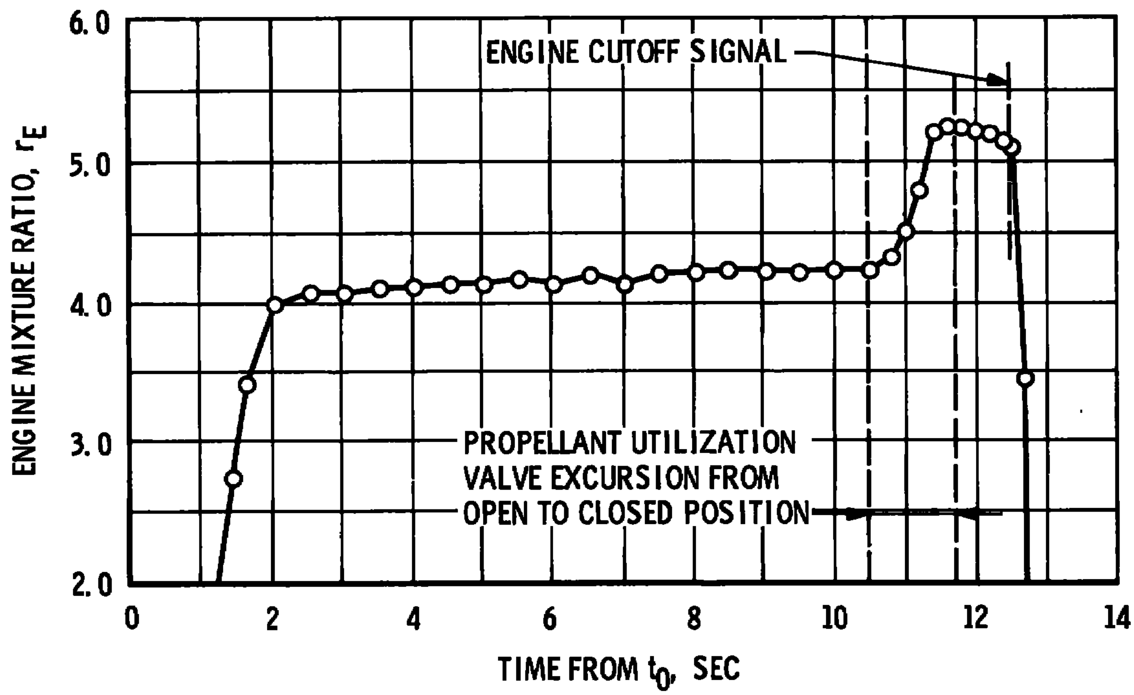


Fig. 32 Fuel Pump Start Transient Performance, Firing 12F



a. Thrust



b. Mixture Ratio

Fig. 33 Thrust and Mixture Ratio Transients during Firing 12A

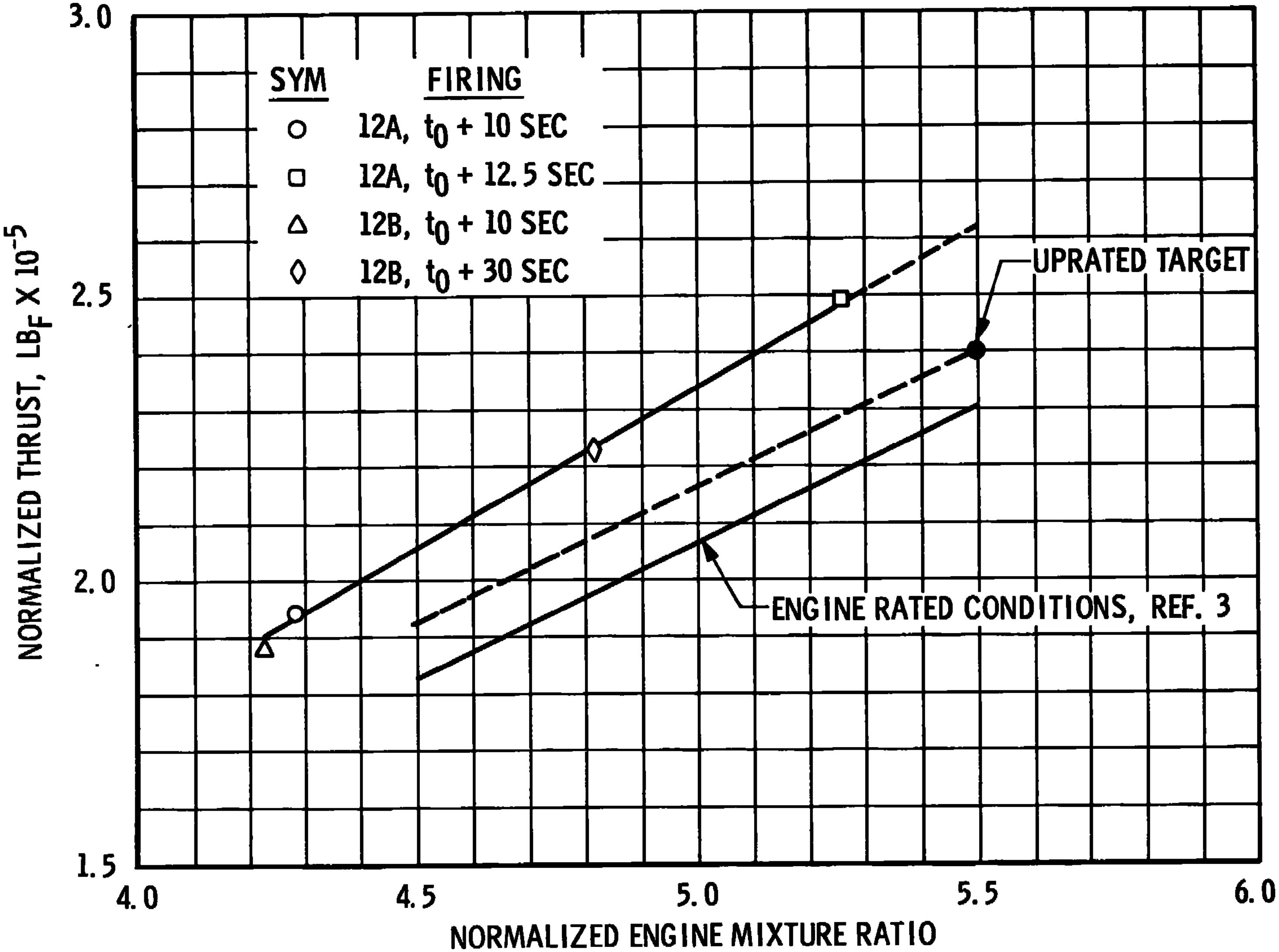
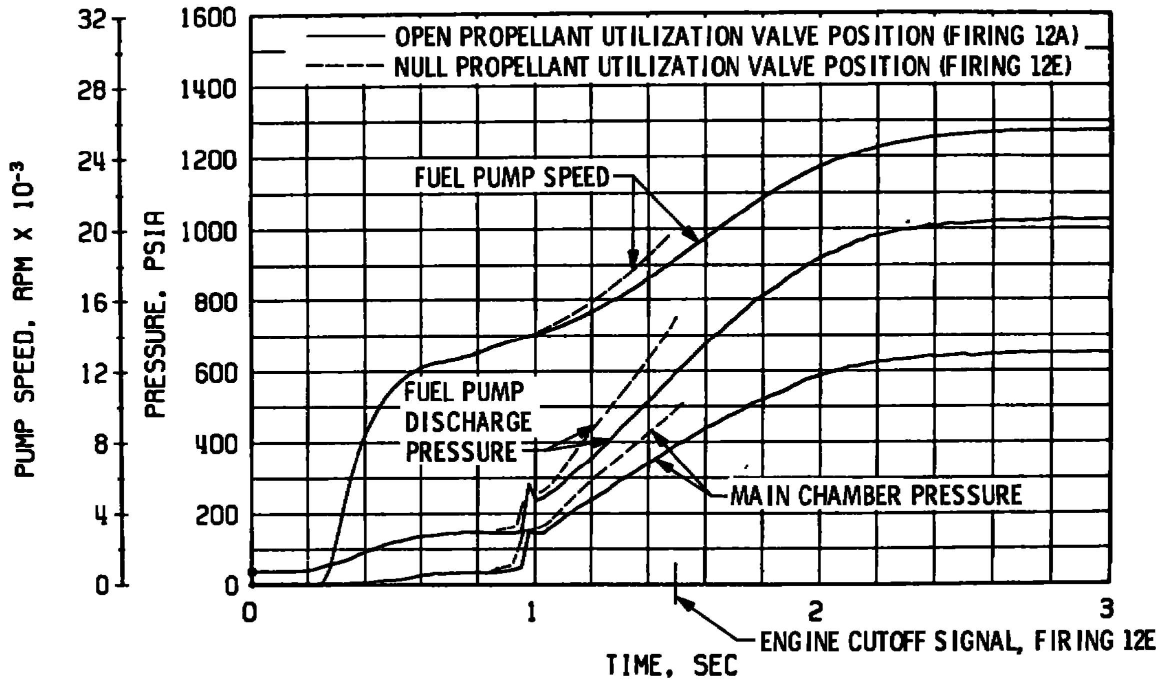
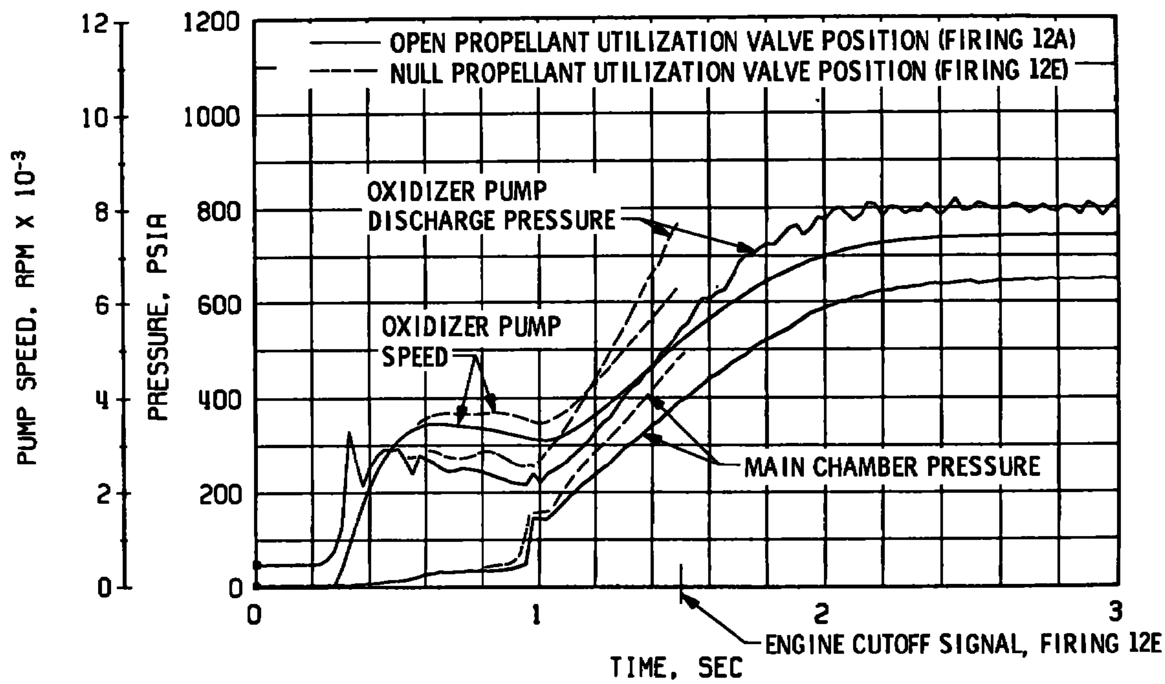


Fig. 34 Engine Normalized Performance

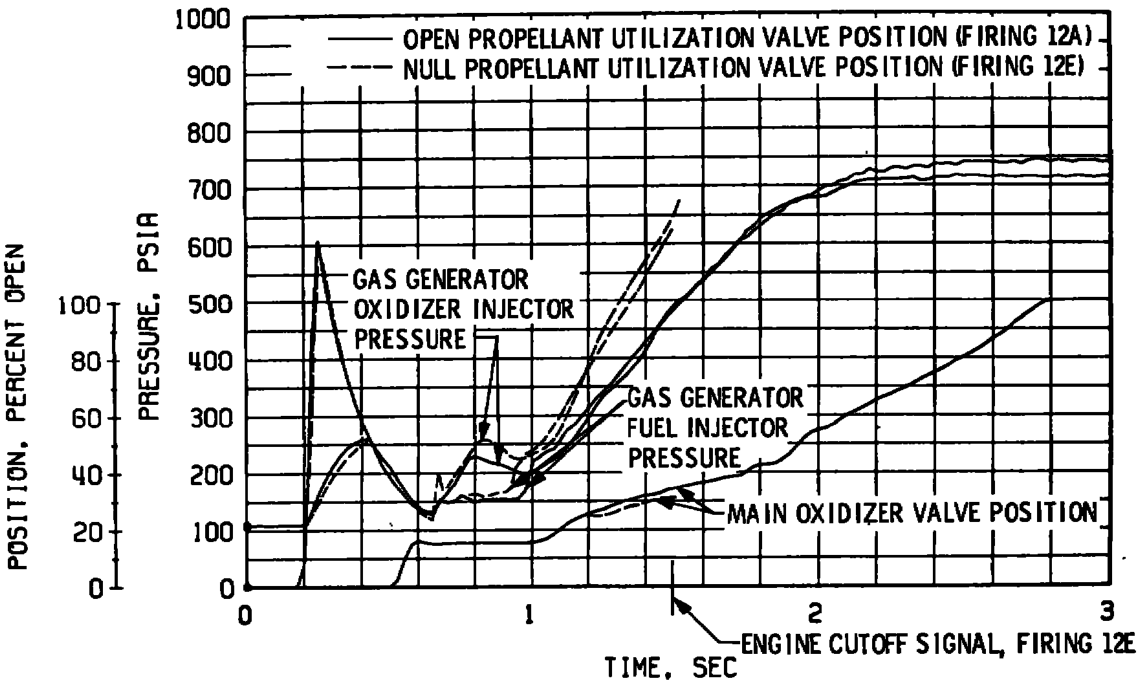


a. Thrust Chamber Fuel System

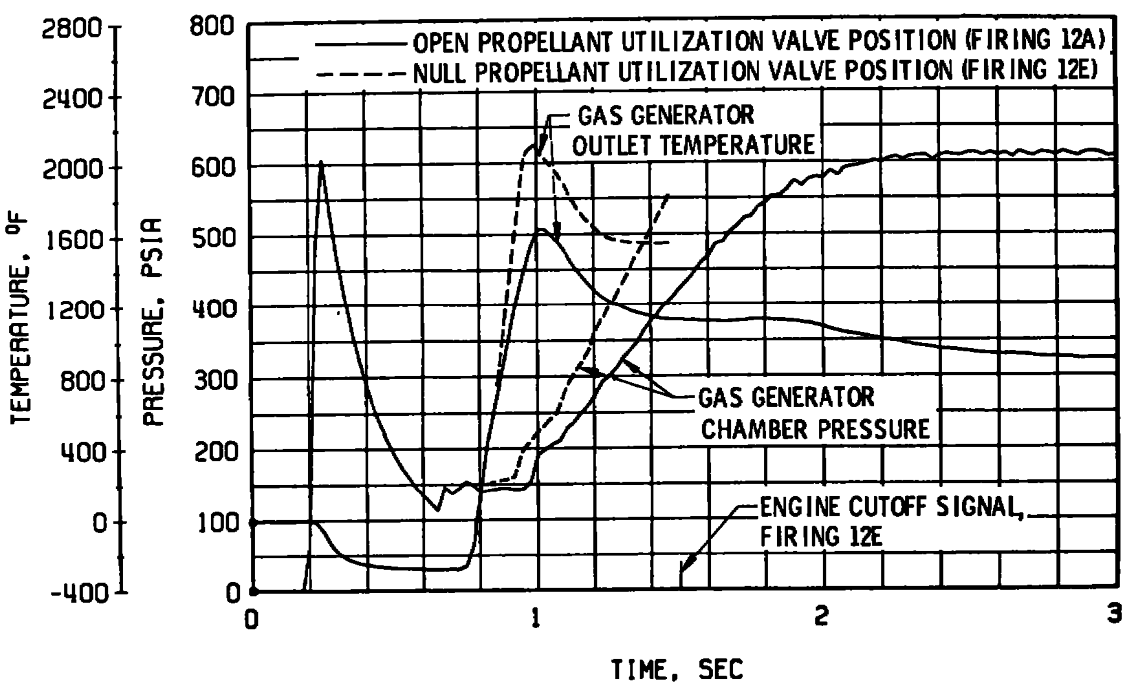


b. Thrust Chamber Oxidizer System

Fig. 35 Effect of Propellant Utilization Valve Position on Engine Start Transients, Firings 12A and 12F



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position



d. Gas Generator Temperature and Chamber Pressure

Fig. 35 Concluded

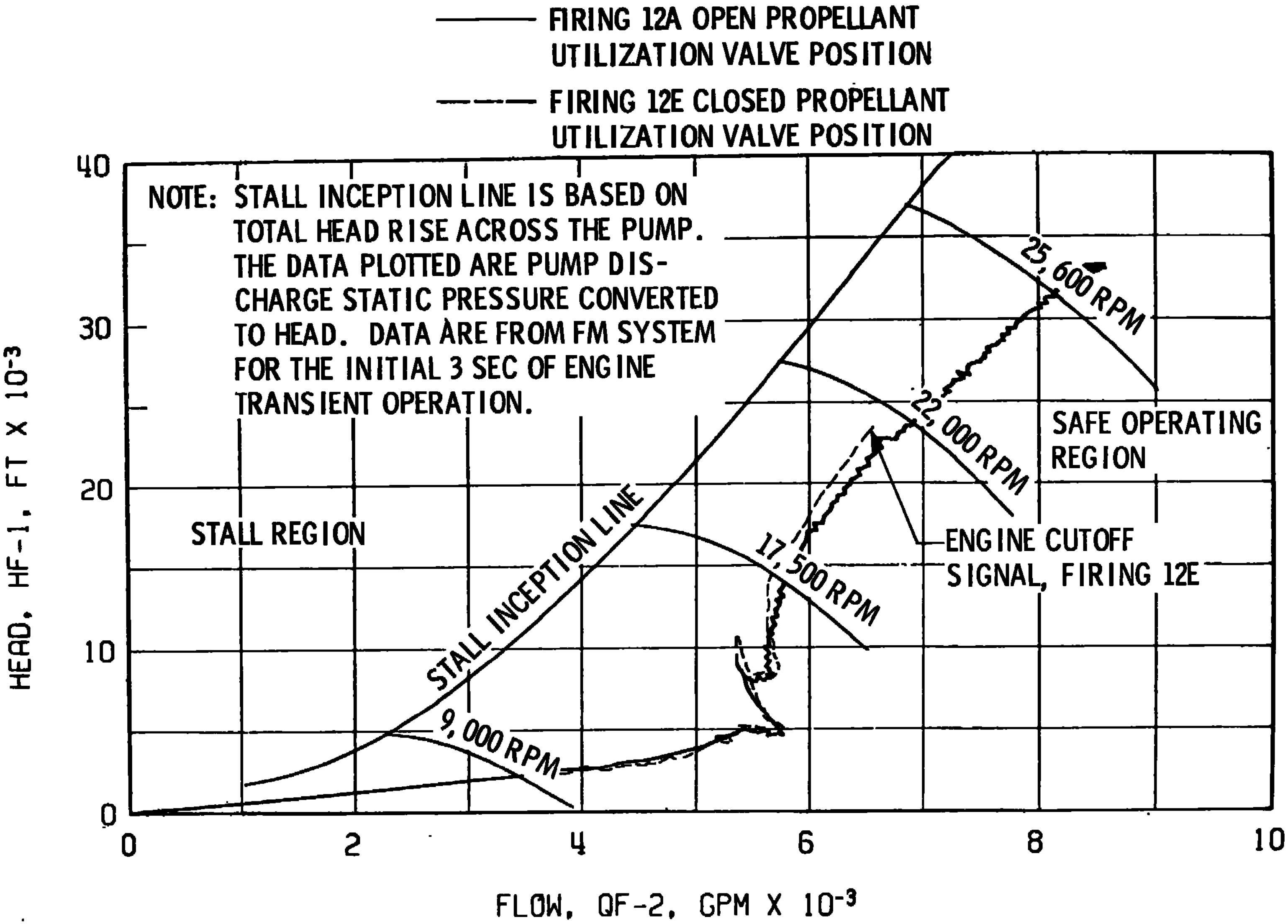


Fig. 36 Effect of Propellant Utilization Valve Position on Fuel Pump Start Transient Performance, Firings 12A and 12F

TABLE I
MAJOR ENGINE COMPONENTS

Part Name	P/N	S/N
Augmented Spark Igniter Assembly	309360-91	4071414
Augmented Spark Igniter Oxidizer Valve	308880	4079065
Auxiliary Flight Instrumentation Package	704090-21	4075163
Electrical Control Package	502670-51	4081748
Fuel Bleed Valve	309034	4084042
Fuel Flowmeter	251225	4074110
Fuel Injector Temperature Transducer	NA5-27441	AA013283F66
Fuel Turbopump Assembly	460390-181	4073647
Gas Generator Control Valve	309040-31	4078292
Gas Generator Fuel Injector and Combustor Assembly	308360-11	4090408
Gas Generator Oxidizer Injector and Poppet Assembly	303323	4092975
Gas Generator Oxidizer Supply Line	408710	3726659
Helium Control Valve (Three-Way)	NA5-27273	372452
Helium Regulator Assembly	558130-111	4061139
Helium Tank Vent Control Valve (Three-Way)	NA5-27273	379313
Ignition Phase Control Valve (Four-Way)	558069	8313398
Main Fuel Valve	409920	4074288
Main Oxidizer Valve	411031-21	4072666
Main-Stage Control Valve (Four-Way)	558069	8284312
Oxidizer Bleed Valve	309029	4084035
Oxidizer Flowmeter	251216	4075154
Oxidizer Turbine Bypass Valve	409940	4081832
Oxidizer Turbopump Assembly	458175-111	6610105
Pressure-Actuated Purge Control Valve	558126	4073862
Pressure-Actuated Shutdown Valve Assembly	558127-11	4074549
Primary Flight Instrumentation Package	704095-21	4074730
Propellant Utilization Valve	251351-51	4075182
Restartable Ignition Detect Probe	NA5-27298T2	203
Start Tank	307579	0098
Start Tank Discharge Valve	304386	4086957
Start Tank Fill/Refill Valve	557998	4091617
Start Tank Vent and Relief Valve	557838-X1	4075413
Thrust Chamber Body	15-205875	4062445
Thrust Chamber Injector Assembly	XEOR-933703	4089721

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter	Date Effective	Comments
Gas Generator Fuel Supply	RD251-4107	0.580 in.	October 7, 1968	Changes Made to Obtain Uprated Performance Level
Gas Generator Oxidizer Supply	RD251-4106	0.332 in.	October 7, 1968	Changes Made to Obtain Uprated Performance Level
Oxidizer Turbine Bypass Valve Nozzle	RD273-8002	1.622 in.	October 7, 1968	Changes Made to Obtain Uprated Performance Level
Main Oxidizer Valve Closing Control	416437-084	8.40 scfm	September 13, 1968	Thermostatic Orifice
Oxidizer Turbine Exhaust Manifold	RD251-9004	10.00 in.	As Delivered to AEDC	---
Augmented Spark Igniter Oxidizer Supply	309358	0.125 in.	June 9, 1968	---
Augmented Spark Igniter Fuel Supply	309355	0.264 in.	September 27, 1968	Change Required because of Uprated Thrust Level

TABLE III
ENGINE MODIFICATIONS

Modification Number	Completion Date	Description of Modification
RFD[1] - AEDC-49-68	October 3, 1968	Development-Type Start Tank Vent and Relief Valve

[1]RFD - Rocketdyne Field Directive

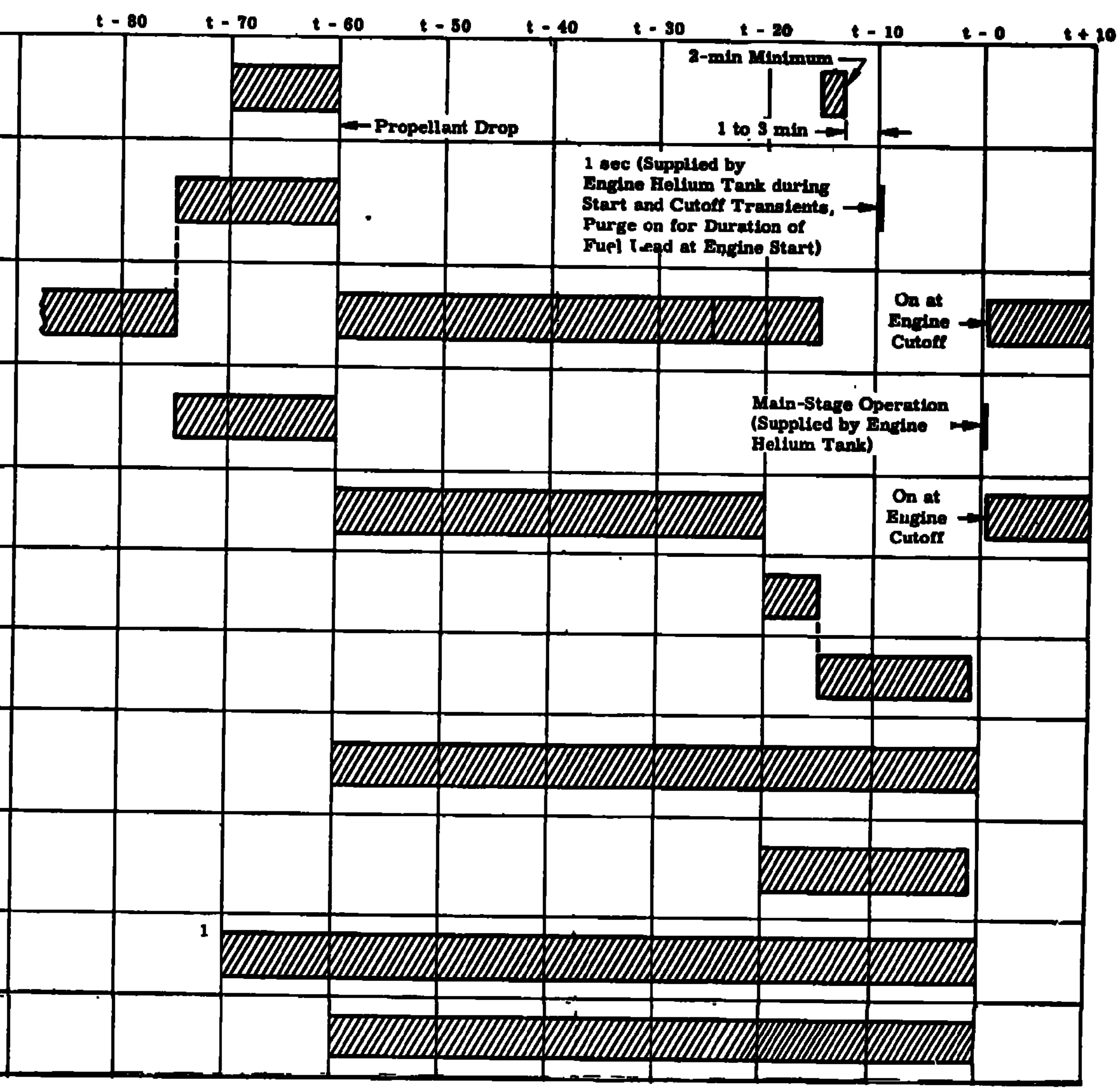
TABLE IV
ENGINE COMPONENT REPLACEMENTS

Replacement	Completion Date	Component Replaced
UCR[1] - 005179	October 6, 1968	Oxidizer Turbine Bypass Valve

[1]UCR - Unsatisfactory Condition Report

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

Turbopump and Gas Generator Purge (Purge Manifold System)	Helium; 82 - 130 psia 50 - 200°F (Nominal 6 scfm at Customer Connect)
Oxidizer Dome and Gas Generator Liquid Oxygen Injector (Engine Pneumatic System)	Helium; 1400 psig 50 - 100°F (Nominal 230 scfm at Customer Connect)
Oxidizer Dome (Facility Line to Port CO3A)	Nitrogen; 415 - 675 psia 100 - 200°F 175 - 230 scfm
Oxidizer Turbopump Intermediate Seal Cavity (Engine Pneumatic System)	Helium; 1400 psig 50 - 200°F 2600 - 7000 scfm
Thrust Chamber Jacket (Customer Connect Panel)	Nitrogen; 165 - 215 psia 100 - 200°F Nominal 100 scfm
	Helium; 55 - 200 psia Ambient Temperature
Thrust Chamber Temperature Conditioning	Helium; 1000-psia Maximum Temperature as Required
Pump Inlet Pressure and Temperature Conditioning	Oxidizer; 35 to 48 psia -298 to 280°F Fuel; 28 to 46 psia -424 to -416°F
Hydrogen Start Tank and Helium Tank Pressure and Temperature Conditioning	Hydrogen; 1200 - 1400 psia -140 to -300°F Helium; 1700 - 3250 psia -140 to -300°F
Crossover Duct Temperature	Helium; -300°F to Ambient
Main Oxidizer Valve Temperature Conditioning	Propellant - Oxidizer



[1]Conditioning Temperature to be Maintained for the Last 30 min of Pre-Fire

TABLE VI
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number: J4-1901-		12A Target	12A Actual	12B Target	12B Actual	12C Target	12C Actual	12D Target	12D Actual	12E Target	12E Actual	12F Target	12F Actual
Time of Day, hr/Firing Date		1118	10/8/68	1221	10/8/68	1406	10/8/68	1547	10/8/68	1636	10/8/68	1715	10/8/68
Pressure Altitude at Engine Start, ft (Ref. 1)		100,000	86,000	100,000	97,000	100,000	97,000	100,000	96,500	100,000	98,500	100,000	100,000
Firing Duration, sec①		32.5	12.522④	32.5	32.571	7.5	7.583	7.5	7.582	⑤	1.478	⑤	1.660
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	41 ± 1	40.9	26.5^{+1}_{-0}	26.8	41 ± 1	40.9	26.5^{+1}_{-0}	26.8	41 ± 1	41.0	41 ± 1	41.3
	Temperature, °F	-421.4 ± 0.4	-421.5	-421.4 ± 0.4	-421.4	-421.4 ± 0.4	-421.6	-421.4 ± 0.4	-421.7	-421.4 ± 0.4	-421.4	-421.4 ± 0.4	-421.4
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	45^{+1}_{-0}	45.5	45^{+1}_{-0}	45.6	45^{+1}_{-0}	46.0	33 ± 1	33.1	45^{+1}_{-0}	45.3	45^{+1}_{-0}	45.2
	Temperature, °F	-295.0 ± 0.4	-294.8	-295.0 ± 0.4	-295.0	-295.0 ± 0.4	-294.8	-295.0 ± 0.4	-295.3	-295.0 ± 0.4	-295.0	-295.0 ± 0.4	-295.1
Start Tank Conditions at Engine Start	Pressure, psia	1400 ± 10	1403	1400 ± 10	1401	1300 ± 10	1305	1200 ± 10	1196	1400 ± 10	1394	1300 ± 10	1306
	Temperature, °F	-270 ± 10	-270	-270 ± 10	-270	-300 ± 10	-301	-140 ± 10	-140	-270 ± 10	-270	-300 ± 10	-300
Helium Tank Conditions at Engine Start	Pressure, psia	---	2129	---	2177	---	2177	---	2220	---	2184	---	2141
	Temperature, °F	---	-269	---	-270	---	-302	---	-134	---	-270	---	-300
Thrust Chamber Temperature Conditions at Engine Start/t_0, °F	Throat, TTC-1P	-150^{+20}_{-10}	-146	-275 ± 25	-277	-150^{+20}_{-10}	-153	-275 ± 25	-279	-150^{+20}_{-10}	-148	-150^{+20}_{-10}	-152
	Average	---	-148	---	-287	---	-164	---	-280	---	-160	---	-160
Crossover Duct Temperature at Engine Start, °F②	TFTD-2	50^{+0}_{-50}	+21	50^{+0}_{-50}	+25	50^{+0}_{-50}	-31⑥	-100 ± 25	-116	50^{+0}_{-50}	+19	50^{+0}_{-50}	+23
	TFTD-3/-4	↓	+30/+32	↓	+32/+35	↓	+19/+22	↓	-94/-88	↓	+29/+32	↓	+28/+33
	TFTD-8	↓	+28	↓	+26	↓	+28	↓	-109	↓	+25	↓	+21
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F③		-150 ± 50	-129	-150 ± 50	-161	-150 ± 50	-129	-150 ± 50	-115	-150 ± 50	-165	-150 ± 50	-173
Fuel Lead Time, sec①		1.00	1.001	1.00	1.003	1.00	1.004	1.00	1.002	1.00	1.002	1.00	1.002
Propellant in Engine Time, min		30	---	30	---	30	---	30	---	30	---	30	---
Propellant Recirculation Time, min		10	---	10	---	10	---	10	---	10	---	10	---
Start Sequence Logic		Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F	TOBS-1	---	+30	---	-1	---	-11	---	-26	---	-24	---	-27
	TOBS-2	---	+11	---	-2	---	+6	---	+6	---	-5	---	-5
	TOBS-2B	---	+31	---	+24	---	+25	---	+30	---	+26	---	+26
Start Tank Discharge Valve Body Temperature at Engine Start, °F		---	+22	---	-44	---	-97	---	-74	---	-56	---	-74
Vibration Safety Counts Duration, msec, and Occurrence Time, sec, from t_0, VSC-1, -2, and -3		--- / ---	17/18/18 / 0.960	--- / ---	26/27/26 / 0.973	--- / ---	16/17/17 / 0.981	--- / ---	9/3/3 28/18/28 / 0.566 1.064	--- / ---	2/6/2 / 0.934	--- / ---	10/14/14 / 0.905
Gas Generator Outlet Temperature, °F	Initial Peak	---	1630	---	1510	---	2060	---	1560	---	2110	---	1920
	Second Peak	---	---	---	---	---	---	---	---	---	---	---	---
Thrust Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0)①		---	0.960	---	0.987	---	0.982	---	0.983	---	0.935	---	0.958
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0)①		---	0.980	---	0.964	---	0.970	---	1.082	---	0.935	---	0.970
Main-Stage Pressure No. 2, sec (Ref. t_0)①		---	1.610	---	1.663	---	1.604	---	1.928	---	1.425	---	1.603
Time Chamber Pressure Attains 550 psia, sec (Ref. t_0)①		---	1.887	---	1.929	---	1.879	---	2.358	---	---	---	---
Propellant Utilization Valve Position, Engine Start/t_0 + 10 sec		Open / Closed	Open / Closed	Open / Null	Open / Null	Open / ---	Open / ---	Open / ---	Open / ---	Null / ---	Null / ---	Open / ---	Open / ---

Notes:
①Data reduced from oscillogram.
②Component conditioning to be maintained within limits for last 15 min before engine start.
③Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.
④Firing 12A was prematurely terminated by the engine safety cutoff system because of fuel turbine overspeed (28,750 rpm).
⑤Engine cutoff signal to be initiated at main-stage pressure signal.
⑥Desired thermal conditioning could not be maintained because of propellant leak.

TABLE VII
ENGINE VALVE TIMINGS

Firing Number J4-1901-	Start																				
	Start Tank Discharge Valve						Main Fuel Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
12A	0.0	0.130	0.112	0.448	0.129	0.245	-1.001	0.083	0.105	0.448	0.051	0.046	0.448	0.592	1.780	0.448	0.104	0.032	0.448	0.184	0.080	0.448	0.229	0.290
12B	0.0	0.135	0.125	0.449	0.131	0.260	-1.003	0.073	0.106	0.449	0.050	0.045	0.449	0.506	1.755	0.449	0.101	0.035	0.449	0.186	0.080	0.449	0.216	0.298
12C	0.0	0.143	0.130	0.445	0.138	0.270	-1.004	0.074	0.113	0.445	0.050	0.048	0.445	0.534	1.784	0.445	0.108	0.032	0.445	0.191	0.107	0.445	0.258	0.288
12D	0.0	0.130	0.120	0.445	0.142	0.265	-1.002	0.084	0.116	0.445	0.049	0.048	0.445	0.532	1.765	0.445	0.115	0.034	0.445	0.185	0.100	0.445	0.242	0.300
12E	0.0	0.139	0.123	0.446	0.135	0.265	-1.002	0.068	0.135	0.446	0.050	0.050	0.446	0.567	---	0.446	0.110	0.033	0.446	0.203	0.110	0.446	0.243	0.300
12F	0.0	0.138	0.125	0.447	0.136	0.265	-1.002	0.070	0.120	0.447	0.045	0.053	0.447	0.524	---	0.447	0.106	0.034	0.447	0.196	0.102	0.447	0.241	0.292
Final Sequence	0.0	0.087	0.093	0.450	0.130	0.240	-1.002	0.047	0.108	0.450	0.048	0.042	0.450	0.550	1.710	0.450	0.078	0.037	0.450	0.141	0.072	0.450	0.204	0.296

Firing Number J4-1901-	Shutdown														
	Main Fuel Valve			Main Oxidizer Valve			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
12A	12.522	0.104	0.320	12.522	0.080	0.179	12.522	0.058	0.015	12.522	0.024	0.015	12.522	0.234	0.630
12B	32.571	0.113	0.330	32.571	0.093	0.180	32.571	0.073	0.015	32.571	0.023	0.015	32.571	0.253	0.595
12C	7.583	0.115	0.360	7.583	0.080	0.170	7.583	0.080	0.020	7.583	0.035	0.015	7.583	0.250	0.700
12D	7.582	0.109	0.335	7.582	0.074	0.170	7.582	0.077	0.022	7.582	0.035	0.018	7.582	0.259	0.702
12E	1.478	0.120	0.315	1.478	---	---	1.478	0.081	0.032	1.478	0.035	0.018	1.478	0.192	0.643
12F	1.660	0.110	0.318	1.660	---	---	1.660	0.081	0.032	1.660	0.038	0.018	1.660	0.198	0.625
Final Sequence	4.405	0.078	0.0225	4.405	0.050	0.125	4.405	0.063	0.024	4.405	0.097	0.043	4.405	0.220	0.630

Notes:
1. All valve signal times are referenced to t_0.
2. Valve delay time is the time required for initial valve movement after the valve "open" or "closed" solenoid has been energized.
3. Final sequence check is conducted without propellants and within 12 hr before testing.
4. Data reduced from oscillogram.

TABLE VIII
ENGINE PERFORMANCE SUMMARY

Firing Number J4-1901-		12B Site	12B Normalized
Overall Engine Performance	Thrust, lb_f	225,800	222,900
	Chamber Pressure, psia	773.9	760.0
	Mixture Ratio	4.798	4.813
	Fuel Weight Flow, lb_m/sec	90.5	88.7
	Oxidizer Weight Flow, lb_m/sec	434.1	427.0
	Total Weight Flow, lb_m/sec	524.6	515.7
Thrust Chamber Performance	Mixture Ratio	4.992	5.011
	Total Weight Flow, lb_m/sec	516.7	507.9
	Characteristic Velocity, ft/sec	8208	8201
Fuel Turbopump Performance	Pump Efficiency, percent	72.8	72.8
	Pump Speed, rpm	27,640	27,390
	Turbine Efficiency, percent	62.5	62.3
	Turbine Pressure Ratio	7.57	7.57
	Turbine Inlet Temperature, °F	1052	1035
	Turbine Weight Flow, lb_m/sec	7.86	7.76
Oxidizer Turbopump Performance	Pump Efficiency, percent	81.0	81.0
	Pump Speed, rpm	8662	8580
	Turbine Efficiency, percent	54.2	53.9
	Turbine Pressure Ratio	2.63	2.63
	Turbine Inlet Temperature, °F	621	610
	Turbine Weight Flow, lb_m/sec	6.74	6.65
Gas Generator Performance	Mixture Ratio	0.852	0.843
	Chamber Pressure, psia	741.6	730.1

Notes:
1. Site data are calculated from test data.
2. Normalized data are corrected to standard pump inlet and engine ambient pressure conditions.
3. Input data are test data averaged from 29 to 30 sec.
4. Site and normalized data were computed using the Rocketdyne PAST 640 modification zero computer program.

APPENDIX III
INSTRUMENTATION

The instrumentation for AEDC test J4-1901-12 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1.

TABLE III-1
INSTRUMENTATION LIST

AEDC Code	Parameter	Tap No.	Range	Micro-sadic	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Current		amp					
ICC	Control		0 to 30	x		x		
IIC	Ignition		0 to 30	x		x		
	Event							
EASIOV	Augmented Spark Igniter Oxidizer Valve		Open/Closed	x		x		
EECL	Engine Cutoff Lockin		On/Off	x		x		
EECO	Engine Cutoff Signal		On/Off	x	x	x		
EES	Engine Start Command		On/Off	x		x		
EFBVC	Fuel Bleed Valve Closed Limit		Open/Closed	x				
EFPVC/O	Fuel Prevalve Closed/Open Limit		Closed/Open	x				
EHCS	Helium Control Solenoid		On/Off	x		x		
EID	Ignition Detected		On/Off	x		x		
EIPCS	Ignition Phase Control Solenoid		On/Off	x		x		
EMCS	Main-Stage Control Solenoid		On/Off	x		x		
EMP-1	Main-Stage Pressure No. 1		On/Off	x		x		
EMP-2	Main-Stage Pressure No. 2		On/Off	x		x		
EOBVC	Oxidizer Bleed Valve Closed Limit		Open/Closed	x				
EOPVC	Oxidizer Prevalve Closed Limit		Closed	x		x		
EOPVO	Oxidizer Prevalve Open Limit		Open	x		x		
ESTDCS	Start Tank Discharge Control Solenoid		On/Off	x	x	x		
RASIS-1	Augmented Spark Igniter Spark No. 1		On/Off			x		
RASIS-2	Augmented Spark Igniter Spark No. 2		On/Off			x		
RGGS-1	Gas Generator Spark No. 1		On/Off			x		
RGGS-2	Gas Generator Spark No. 2		On/Off			x		
	Flows		gpm					
QF-1A	Fuel	PFF	0 to 9000	x		x		
QF-2	Fuel	PFFA	0 to 9000	x	x	x		
QF-1SAM	Fuel Flow Stall Approach Monitor		0 to 9000	x		x		
QFRP	Fuel Recirculation		0 to 160	x				
QO-1A	Oxidizer	POF	0 to 3000	x		x		
QO-2	Oxidizer	POFA	0 to 3000	x	x	x		
QORP	Oxidizer Recirculation		0 to 50	x				
	Position		Percent Open					
LFVT	Main Fuel Valve		0 to 100	x		x		
LGGVT	Gas Generator Valve		0 to 100	x		x		
LOTBVT	Oxidizer Turbine Bypass Valve		0 to 100	x		x		
LOVT	Main Oxidizer Valve		0 to 100	x		x		
LPUTOP	Propellant Utilization Valve		0 to 100	x		x	x	
LSTDVT	Start Tank Discharge Valve		0 to 100	x		x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Microsadic	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Pressure		psia					
PA1	Test Cell		0 to 0.5	x		x		
PA2	Test Cell		0 to 1.0	x	x			
PA3	Test Cell		0 to 5.0	x			x	
PC-1P	Thrust Chamber	CG1	0 to 1000	x				
PC-3	Thrust Chamber	CG1A	0 to 1000	x	x	x		
PCBO-1	Constant Bleed Orifice		0 to 50	x				
PCDP	Crossover Duct Purge		0 to 100	x				
PCGG-1P	Gas Generator Chamber		0 to 1000	x	x	x		
PCGG-2	Gas Generator Chamber	GG1A	0 to 1000	x				
PFBL	Fuel Bleed Line		0 to 100	x		x		
PFJ-1A	Main Fuel Injection	CF2	0 to 1000	x		x		
PFJGG-1A	Gas Generator Fuel Injection	GF4	0 to 1000	x				
PFJGG-2	Gas Generator Fuel Injection	GF4	0 to 1000	x		x		
PFPC-1A	Fuel Pump Balance Piston Cavity	PF5	0 to 1000	x				
PFPD-1P	Fuel Pump Discharge	PF3	0 to 1500	x				
PFPD-2	Fuel Pump Discharge	PF2	0 to 1500	x	x	x		
PFPI-1	Fuel Pump Inlet		0 to 100	x		x		x
PFPI-2	Fuel Pump Inlet		0 to 100	x		x		x
PFPI-3	Fuel Pump Inlet		0 to 200		x			
PFPPSD-1	Fuel Pump Primary Seal Drain		0 to 200	x				
PFRPO	Fuel Recirculation Pump Outlet		0 to 60	x				
PFRPR	Fuel Recirculation Pump Return		0 to 50	x				
PFST-1P	Fuel Start Tank	TF1	0 to 1500	x		x		
PFST-2	Fuel Start Tank	TF1	0 to 1500	x				x
PFUT	Fuel Tank Ullage		0 to 100	x				
PFVI	Fuel Tank Pressurization Line Nozzle Inlet		0 to 1000	x				
PFVL	Fuel Tank Pressurization Line Nozzle Throat		0 to 1000	x				
PHECMO	Pneumatic Control Module Outlet		0 to 750	x				
PHEOP	Oxidizer Recirculation Pump Purge		0 to 150	x				
PHET-1P	Helium Tank	NN1	0 to 3500	x		x		
PHET-2	Helium Tank	NN1	0 to 3500	x				x
PHRO-1A	Helium Regulator Outlet	NN2	0 to 750	x				
POJ-1A	Main Oxidizer Injection	CO3	0 to 1000	x		x		
POJ-2	Main Oxidizer Injection	CO3A	0 to 1000	x		x		
POJ-3	Main Oxidizer Injection		0 to 2000		x			

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-sadic	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Pressure (Continued)		psia					
POJGG-1A	Gas Generator Oxidizer Injection	GO5	0 to 1000	x		x		
POJGG-2	Gas Generator Oxidizer Injection	GO5	0 to 1000	x				
POPBC-1A	Oxidizer Pump Bearing Coolant	PO7	0 to 500	x				
POPD-1P	Oxidizer Pump Discharge	PO3	0 to 1500	x				
POPD-2	Oxidizer Pump Discharge	PO2	0 to 1500	x	x	x		
POPI-1	Oxidizer Pump Inlet		0 to 100	x				x
POPI-2	Oxidizer Pump Inlet		0 to 200	x				x
POPI-3	Oxidizer Pump Inlet		0 to 100			x		
POPSC-1A	Oxidizer Pump Primary Seal Cavity	PO6	0 to 50	x				
PORPO	Oxidizer Recirculation Pump Outlet		0 to 115	x				
PORPR	Oxidizer Recirculation Pump Return		0 to 100	x				
POTI-1A	Oxidizer Turbine Inlet	TG3	0 to 200	x				
POTO-1A	Oxidizer Turbine Outlet	TG4	0 to 100	x				
POUT	Oxidizer Tank Ullage		0 to 100	x				
POVCC	Main Oxidizer Valve Closing Control		0 to 500	x				
POVI	Oxidizer Tank Pressurization Line Nozzle Inlet		0 to 1000	x				
POVL	Oxidizer Tank Pressurization Line Nozzle Throat		0 to 1000	x				
PPUVI-1A	Propellant Utilization Valve Inlet	PO8	0 to 1500	x				
PPUVO-1A	Propellant Utilization Valve Outlet	PO9	0 to 500	x				
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 100	x				
PTCP	Thrust Chamber Purge		0 to 1000	x				
PTPP	Turbopump and Gas Generator Purge		0 to 250	x				
	Speeds		rpm					
NFP-1P	Fuel Pump	PFV	0 to 30,000	x	x	x		
NFRP	Fuel Recirculation Pump		0 to 15,000	x				
NOP-1P	Oxidizer Pump	POV	0 to 12,000	x	x	x		
NORP	Oxidizer Recirculation Pump		0 to 15,000	x				
	Temperatures		°F					
TA1	Test Cell (North)		-50 to +800	x				
TA2	Test Cell (East)		-50 to +800	x				
TA3	Test Cell (South)		-50 to +800	x				
TA4	Test Cell (West)		-50 to +800	x				
TAIP-1A	Auxiliary Instrument Package		-300 to +200	x				
TAIPAA	Auxiliary Instrument Package Area Ambient		-200 to +500	x				
TCDP	Crossover Duct Purge		-150 to +150	x				

TABLE III-1 (Continued)

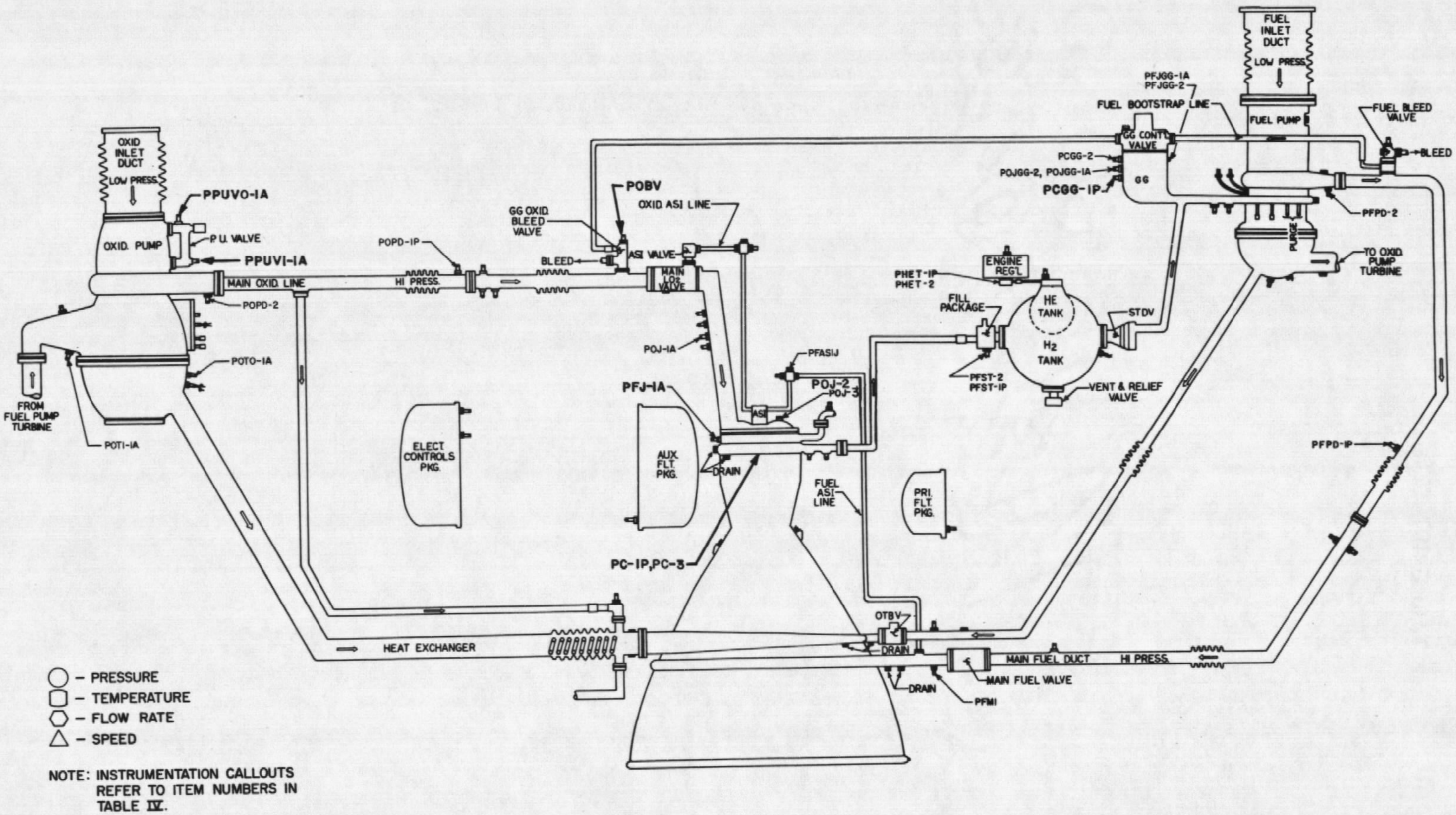
AEDC Code	Parameter	Tap No.	Range	Micro-sadic	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures (Continued)		°F					
TECP-1P	Electrical Controls Package	NST1A	-300 to -200	x			x	
TEHAA	Engine Handler Attach Area Ambient		-200 to +500	x				
TFASIL-2	Augmented Spark Igniter Fuel Line Skin		-400 to +300	x				
TFASIL-4	Augmented Spark Igniter Fuel Line Skin		-425 to +500	x				
TFBV-1A	Fuel Bleed Valve	GFT1	-425 to -375	x				
TFD-1	Fire Detection		0 to 1000	x			x	
TFDAA	Fuel High Pressure Duct Area Ambient		-200 to +500	x				
TFJ-1P	Main Fuel Injection	CFT2	-425 to +250	x		x		
TFJ-2	Main Fuel Injection		-450 to +250	x				
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -400	x	x	x		
TFPD-2	Fuel Pump Discharge	PFT1	-425 to -400	x				
TFPI-1	Fuel Pump Inlet		-425 to -400	x				
TFPI-2	Fuel Pump Inlet		-425 to -400	x				x
TFRPO	Fuel Recirculation Pump Outlet		-425 to -350	x				
TFRPR	Fuel Recirculation Pump Return Line		-425 to -250	x				
TFRT-1	Fuel Tank		-425 to -410	x				
TFRT-3	Fuel Tank		-425 to -410	x				
TFST-1P	Fuel Start Tank	TFT1	-350 to +100	x				
TFST-2	Fuel Start Tank	TFT1	-350 to +100	x			x	
TFTD-2	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-4	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-8	Fuel Turbine Discharge Duct		-22 to -1400	x			x	
TFTO	Fuel Turbine Outlet	TFT2	0 to 1800	x				
TFTSD-1	Fuel Turbine Seal Drain Line		-300 to +100	x				
TGGO-1A and 2	Gas Generator Outlet	GGT1	0 to 2500	x		x	x	
TGGVRS	Gas Generator Valve Retaining Screw		-100 to -100	x				
THET-1P	Helium Tank	NNT1	-350 to +100	x				x
TNODP	Oxidizer Dome Purge		0 to +300	x				
TOASIL-1	Augmented Spark Igniter Oxidizer Line Skin		-425 to +500	x				
TOASIL-2	Augmented Spark Igniter Oxidizer Line Skin		-400 to +300	x				
TOBS-1	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2B	Oxidizer Bootstrap Line		-300 to +250	x				
TOBV-1A	Oxidizer Bleed Valve	GOT2	-300 to -250	x				
TODAA	Oxidizer Dome Area Ambient		-200 to +500	x				
TODS-1	Oxidizer Dome Skin		-300 to +100	x			x	
TODS-2	Oxidizer Dome Skin		-300 to +100	x			x	

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-sadic	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures (Continued)		°F					
TOPS-1A	Oxidizer Pump Bearing Coolant	POT4	-300 to -250	x				
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x	x	x	x	
TOPD-2	Oxidizer Pump Discharge	POT3	-300 to -250	x				
TOPI-1	Oxidizer Pump Inlet		-310 to -270	x				x
TOPI-2	Oxidizer Pump Inlet		-310 to -270	x				x
TORPO	Oxidizer Recirculation Pump Outlet		-300 to -250	x				
TORPR	Oxidizer Recirculation Pump Return		-300 to -140	x				
TORT-1	Oxidizer Tank		-300 to -287	x				
TORT-1B	Oxidizer Tank		-300 to -287	x				
TORT-3	Oxidizer Tank		-300 to -287	x				
TOTI-1P	Oxidizer Turbine Inlet	TGT3	-300 to 1200	x			x	
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000	x				
TOVL	Oxidizer Tank Pressurization Line Nozzle Throat		-300 to +100	x				
TPIP-1P	Primary Instrument Package		-300 to +200	x				
TPIPAA	Primary Instrument Package Area Ambient		-200 to +500	x				
TSC2-1	Thrust Chamber Skin		-300 to +500	x				
TSC2-12	Thrust Chamber Skin		-300 to +500	x				
TSC2-13	Thrust Chamber Skin		-300 to +500	x			x	
TSC2-17	Thrust Chamber Skin		-300 to +500	x				
TSC2-20	Thrust Chamber Skin		-300 to +500	x				
TSC2-24	Thrust Chamber Skin		-300 to +500	x				
TSOVC-1	Oxidizer Valve Actuator Cap	NST1	-325 to +150	x			x	
TSTDVAA	Start Tank Discharge Valve Area Ambient		-200 to +500	x				
TSTDVDL	Start Tank Discharge Valve Drain Line Port		-100 to +200	x				
TSTDVOC	Start Tank Discharge Valve Opening Control Port		-300 to +200	x				
TTC-1P	Thrust Chamber Jacket (Control)	CS1	-425 to +500	x			x	
TTC-2	Thrust Chamber Jacket	CS1A	-425 to +100	x				
TTCP	Thrust Chamber Purge		-346 to +504	x				
TTPP	Turbopump Purge		-150 to +150	x			x	

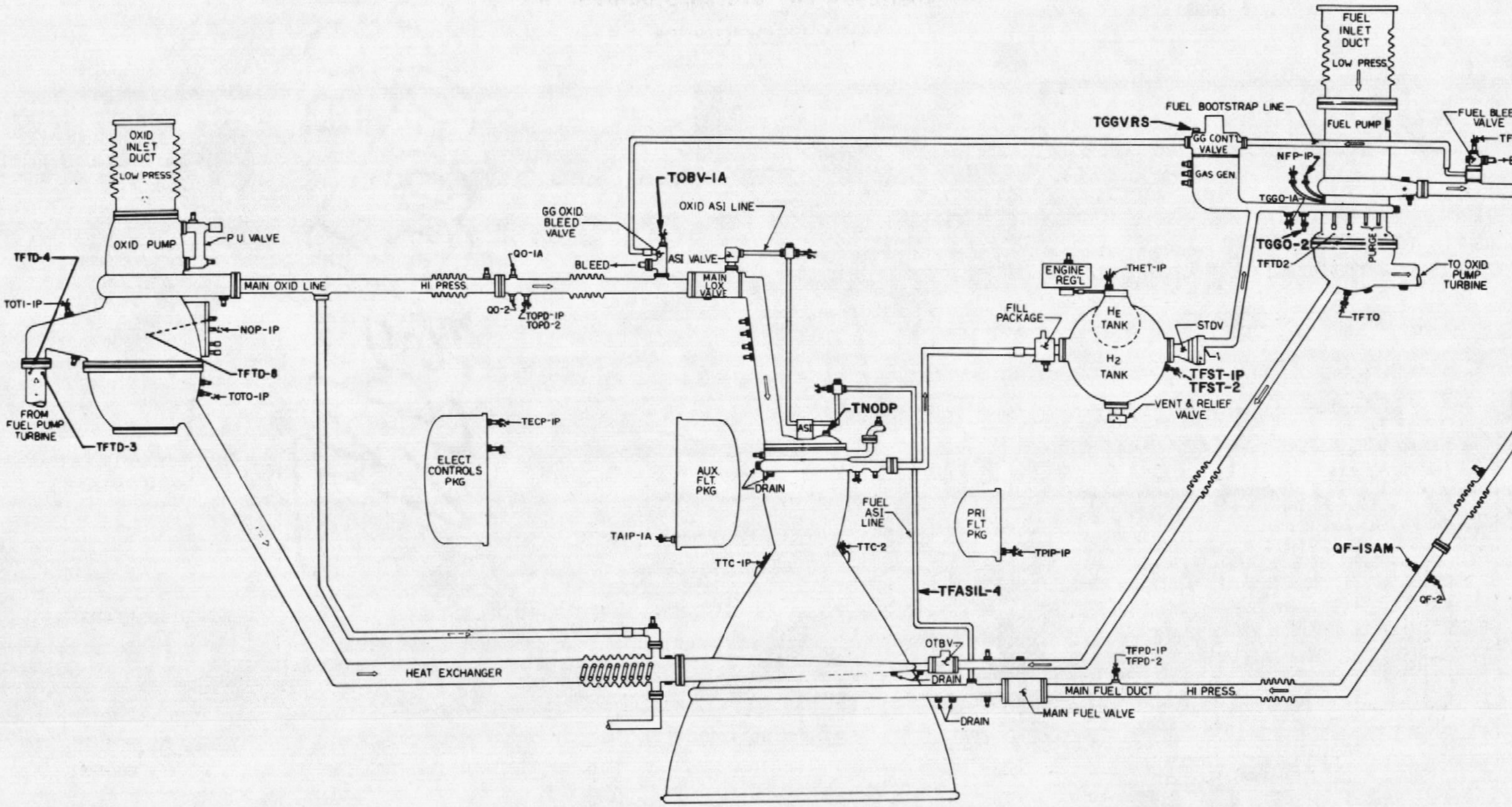
TABLE III-1 (Concluded)

AEDC Code	Parameter	Tap No.	Range	Micro-sadic	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Vibrations		g's					
UASIF-1	Augmented Spark Igniter Fuel Orifice Block Tangential		±150		x			
UASIV-1	Augmented Spark Igniter Oxidizer Valve Axial		±150		x			
UASIV-3	Augmented Spark Igniter Oxidizer Valve Tangential		±150		x			
UFPR	Fuel Pump Radial 90 deg		±300		x	x		
UMFV-1	Main Fuel Valve Radial		±150		x			
UMFV-3	Main Fuel Valve Tangential		±150		x			
UOPR	Oxidizer Pump Radial 90 deg		±200		x	x		
UOTBV-1	Oxidizer Turbine Bypass Valve Axial		±150		x			
UTCD-1	Thrust Chamber Dome		±500		x	x		
UTCD-2	Thrust Chamber Dome		±500		x	x		
UTCD-3	Thrust Chamber Dome		±500		x			
UTCD-4	Thrust Chamber Dome		±1000			x		
U1VBC	No. 1 Vibration Safety Counts		On/Off			x		
U2VBC	No. 2 Vibration Safety Counts		On/Off			x		
U3VSC	No. 3 Vibration Safety Counts		On/Off			x		
	Voltage		volts					
VCB	Control Bus		0 to 36	x		x		
VIB	Ignition Bus		0 to 36	x		x		
VIDA	Ignition Detect Amplifier		9 to 16	x		x		
VFUTEP	Propellant Utilization Valve Excitation		0 to 8	x				

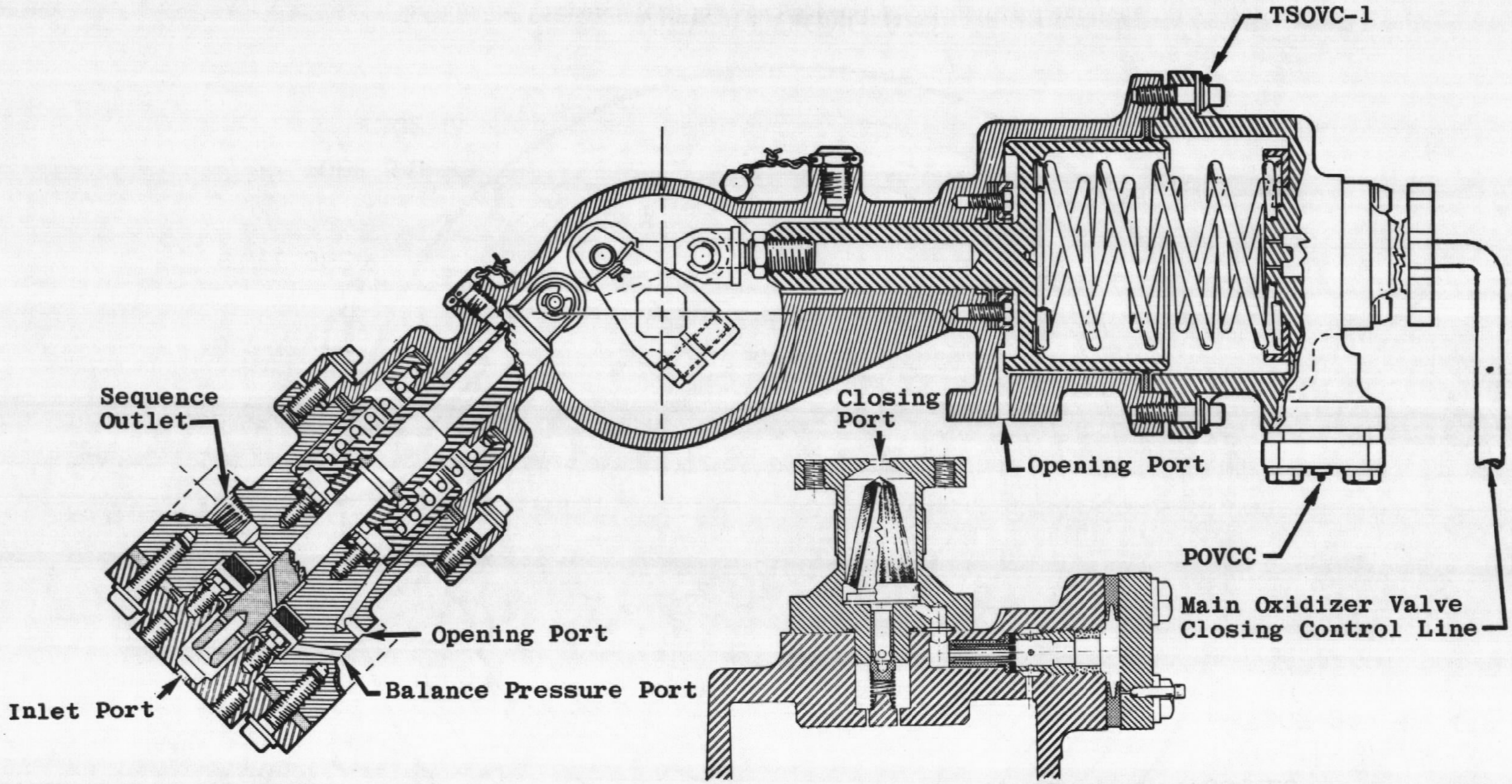


a. Engine Pressure Tap Locations

Fig. III-1 Instrumentation Locations

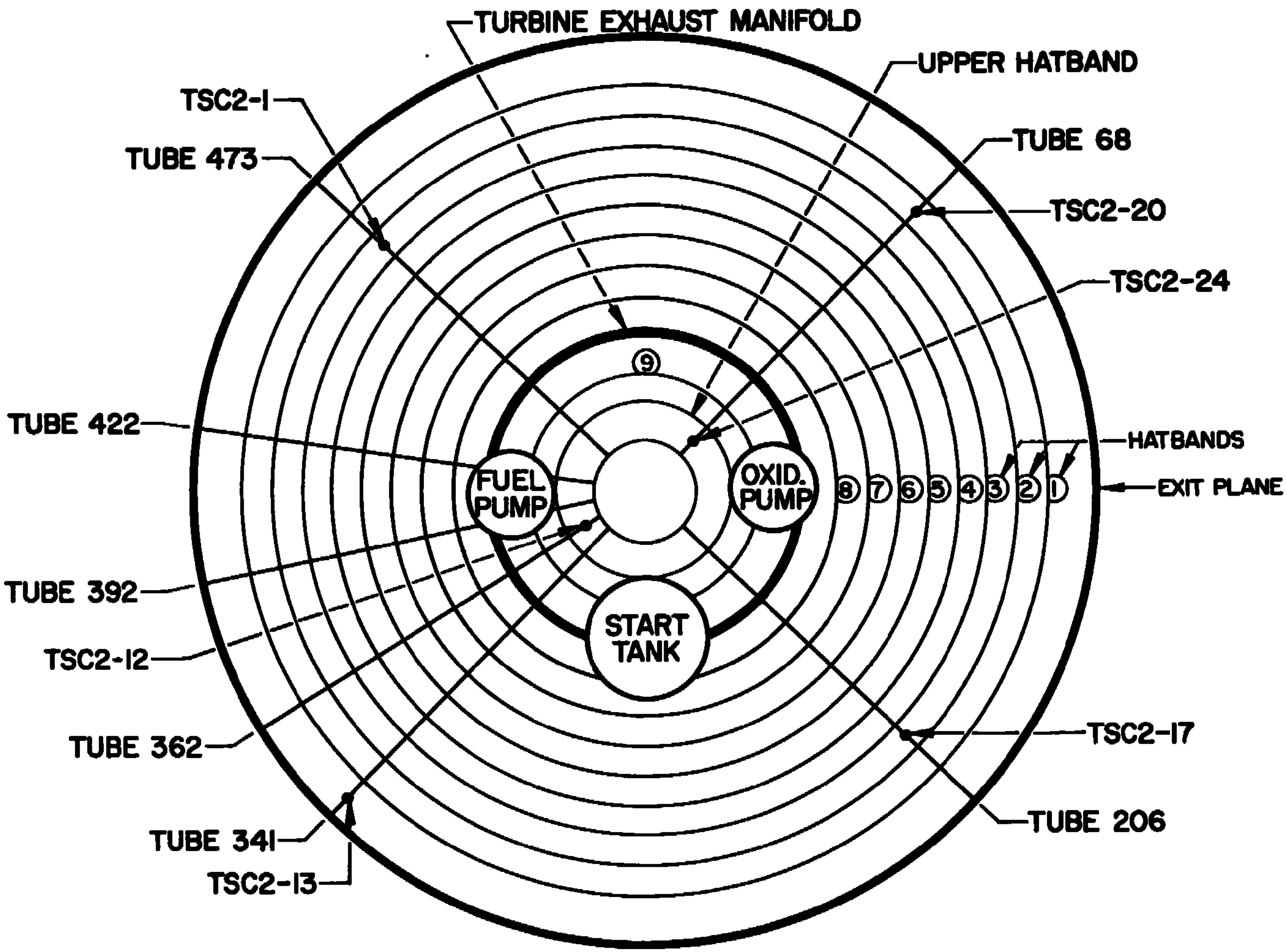


b. Engine Temperature, Flow, and Speed Instrumentation Locations
Fig. III-1 Continued



c. Main Oxidizer Valve

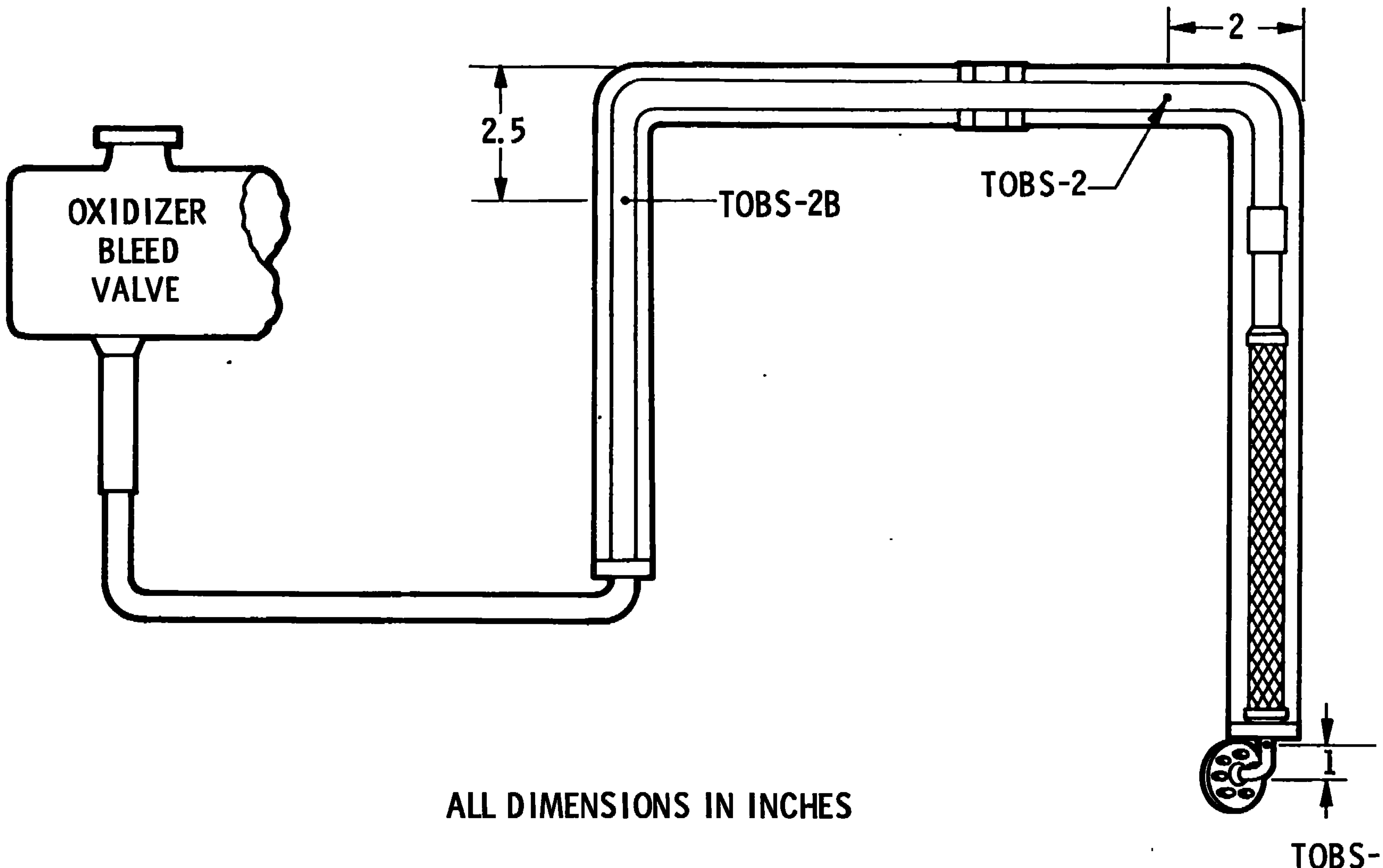
Fig. III-1 Continued



VIEW LOOKING AFT

d. Thrust Chamber

Fig. III-1 Continued



e. Gas Generator Oxidizer Supply Line

Fig. III-1 Concluded

APPENDIX IV
METHOD OF CALCULATIONS (PERFORMANCE PROGRAM)

TABLE IV-1
PERFORMANCE PROGRAM DATA INPUTS

Item No.	Parameter
1	Thrust Chamber (Injector Face) Pressure, psia
2	Thrust Chamber Fuel and Oxidizer Injection Pressures, psia
3	Thrust Chamber Fuel Injection Temperature, °F
4	Fuel and Oxidizer Flowmeter Speeds, Hz
5	Fuel and Oxidizer Engine Inlet Pressures, psia
6	Fuel and Oxidizer Pump Discharge Pressures, psia
7	Fuel and Oxidizer Engine Inlet Temperatures, °F
8	Fuel and Oxidizer (Main Valves) Temperatures, °F
9	Propellant Utilization Valve Center Tap Voltage, volts
10	Propellant Utilization Valve Position, volts
11	Fuel and Oxidizer Pump Speeds, rpm
12	Gas Generator Chamber Pressure, psia
13	Gas Generator (Bootstrap Line at Bleed Valve) Temperature, °F
14	Fuel* and Oxidizer Turbine Inlet Pressure, psia
15	Oxidizer Turbine Discharge Pressure, psia
16	Fuel and Oxidizer Turbine Inlet Temperature, °F
17	Oxidizer Turbine Discharge Temperature, °F

*At AEDC, fuel turbine inlet pressure is calculated from gas generator chamber pressure.

NOMENCLATURE

A	Area, in.^{2}
B	Horsepower
C	Coefficient
C*	Characteristic velocity, ft/sec
D	Diameter, in.
F	Thrust, lb_f
H	Head, ft
h	Enthalpy, Btu/lb_m
I	Impulse
M	Molecular weight
N	Speed, rpm
P	Pressure, psia
Q	Flow rate, gpm
R	Resistance, sec^2/ft^3-in.^{2}
r	Mixture ratio, O/F
T	Temperature, °F
TC*	Theoretical characteristic velocity, ft/sec
W	Weight flow, lb/sec
Z	Differential pressure, psi
β	Ratio
γ	Ratio of specific heats
η	Efficiencies
θ	Degrees
ρ	Density, lb/ft^3

SUBSCRIPTS

A	Ambient
AA	Ambient at thrust chamber exit
B	Bypass nozzle

BIR	Bypass nozzle inlet (Rankine)
BNI	Bypass nozzle inlet (total)
C	Thrust chamber
CF	Thrust chamber, fuel
CO	Thrust chamber, oxidizer
CV	Thrust chamber, vacuum
E	Engine
EF	Engine fuel
EM	Engine measured
EO	Engine oxidizer
EV	Engine, vacuum
e	Exit
em	Exit measured
F	Thrust
FM	Fuel measured
FV	Thrust, vacuum
f	Fuel
G	Gas generator
GF	Gas generator fuel
GO	Gas generator oxidizer
H1	Hot gas duct No. 1
H1R	Hot gas duct No. 1 (Rankine)
H2R	Hot gas duct No. 2 (Rankine)
IF	Inlet fuel
IO	Inlet oxidizer
ITF	Isentropic turbine fuel
ITO	Isentropic turbine oxidizer
N	Nozzle
NB	Bypass nozzle (throat)

NV	Nozzle, vacuum
O	Oxidizer
OC	Oxidizer pump calculated
OF	Outlet fuel pump
OFIS	Outlet fuel pump isentropic
OM	Oxidizer measured
OO	Oxidizer outlet
PF	Pump fuel
PO	Pump oxidizer
PUVO	Propellant utilization valve oxidizer
RNC	Ratio bypass nozzle, critical
SC	Specific, thrust chamber
SCV	Specific thrust chamber, vacuum
SE	Specific, engine
SEV	Specific, engine vacuum
T	Total
TEF	Turbine exit fuel
TEFS	Turbine exit fuel (static)
TF	Fuel turbine
TIF	Turbine inlet fuel (total)
TIFM	Turbine inlet, fuel, measured
TIFS	Turbine inlet fuel isentropic
TIO	Turbine inlet oxidizer
TO	Turbine oxidizer
t	Throat
V	Vacuum
v	Valve
XF	Fuel tank repressurant
XO	Oxidizer tank repressurant

PERFORMANCE PROGRAM EQUATIONS

THRUST

Thrust Chamber, Vacuum

$$F_{CV} = C(P_c - 15)^2 + B(P_c - 15) + A$$

where: P_c = Measured Chamber Pressure
$A = -6762.8867$
$B = 288.0039$
$C = 0.0180$

Empirical Determination from Curve Fit of Thrust versus P_C

Thrust Chamber

$$F_C = F_{CV} - P_{AA} A_e$$

$$A_e = A_{em} + 12.8$$

P_{AA} = Measured Cell Pressure

Engine, Vacuum

$$F_{EV} = F_{CV}$$

Engine

$$F_E = F_C$$

MIXTURE RATIO

Engine

$$r_E = \frac{W_{EO}}{W_{EF}}$$

$$W_{EO} = W_{OM} - W_{XO}$$

$$W_{EF} = W_{FM} - W_{XF}$$

Thrust Chamber

$$r_C = \frac{W_{CO}}{W_{CF}}$$

$$W_{CO} = W_{OM} - W_{XO} - W_{GO}$$

$$W_{CF} = W_{FM} - W_{XF} - W_{GF}$$

W_{XO} = Standard 0.9 lb/sec

W_{XF} = Standard 2.1 lb/sec

$$W_{GO} = W_T - W_{GF}$$

$$W_{GF} = \frac{W_T}{1 + r_G}$$

$$W_T = \frac{P_{TIF}\ A_{TIF}\ K_7}{TC^*_{TIF}}$$

$$K_7 = 32.174$$

Normalized engine and thrust chamber vacuum data calculated as measured, except all flows are normalized using standard inlet pressures, temperatures, and densities listed below:

$$P_{IO}\ STD = 39\ psia$$

$$P_{IF}\ STD = 30\ psia$$

$$\rho_{IO}\ STD = 70.79\ lb/ft^3$$

$$\rho_{IF}\ STD = 4.40\ lb/ft^3$$

$$T_{IO}\ STD = -295.2°F$$

$$T_{IF}\ STD = 422.5°F$$

SPECIFIC IMPULSE

Engine

$$I_{SE} = \frac{F_E}{W_E}$$

$$W_E = W_{EO} + W_{EF}$$

Engine, Vacuum

$$I_{SEV} = \frac{F_{EV}}{W_{EV}}$$

$W_{EV} = W_E$ Normalized using standard inlet pressures, temperatures, and densities

Chamber

$$I_{SC} = \frac{F_C}{W_C}$$

$$W_C = W_{CO} + W_{CF}$$

Chamber, Vacuum

$$I_{SCV} = \frac{F_{CV}}{W_{CV}}$$

$W_{CV} = W_C$ Normalized using standard inlet pressures, temperatures, and densities

CHARACTERISTIC VELOCITY

Thrust Chamber

$$C^* = \frac{K_7 P_C A_t}{W_C}$$

$$K_7 = 32.174$$

Thrust Chamber, Vacuum

$$C_V^* = \frac{K_7 P_{CV} A_t}{W_{CV}}$$

$$K_7 = 32.174$$

Nozzle

$$C_N^* = \frac{C^*}{K_6}$$

$$K_6 = 1.086$$

Nozzle, Vacuum

$$C_{NV}^* = \frac{C_V^*}{K_6}$$

$$K_6 = 1.086$$

THRUST COEFFICIENT

Engine

$$C_F = \frac{F_C}{P_C A_t}$$

Engine, Vacuum

$$C_{FV} = \frac{F_{CV}}{P_C A_t}$$

DEVELOPED PUMP HEAD

Oxidizer

$$H_O = K_4 \left(\frac{P_{OO}}{\rho_{OO}} - \frac{P_{IO}}{\rho_{IO}}\right)$$

$$K_4 = 144$$

ρ = National Bureau of Standards Values f(P,T)

Fuel

$$H_F = 778.16\, \Delta h_{OFIS}$$

$$\Delta h_{OFIS} = h_{OFIS} - h_{IF}$$

$$h_{OFIS} = f(P,T)$$

$$h_{IF} = f(P,T)$$

Fuel and Oxidizer Vacuum

Conditions normalized using standard inlet pressures, temperatures, and densities.

PUMP EFFICIENCIES

Fuel, Isentropic

$$\eta_F = \frac{h_{OF\,IS} - h_{IF}}{h_{OF} - h_{IF}}$$

$$h_{OF} = f(P_{OF}, T_{OF})$$

Oxidizer, Isentropic

$$\eta_O = \eta_{OC}\, Y_O$$

$$\eta_{OC} = K_{40} \left(\frac{Q_{PO}}{N_O}\right)^2 + K_{50} \left(\frac{Q_{PO}}{N_O}\right) + K_{60}$$

$$Y_O = 1.000$$

$$K_{40} = -5.053 \qquad K_{50} = 3.861 \qquad K_{60} = 0.0733$$

TURBINES

Oxidizer, Efficiency

$$\eta_{TO} = \frac{B_{TO}}{B_{ITO}}$$

$$B_{TO} = K_5 \frac{W_{PO}\ H_O}{\eta_O}$$

$$K_5 = 0.001818$$

$$W_{PO} = W_{OM} + W_{PUVO}$$

$$W_{PUVO} = \sqrt{\frac{Z_{PUVO}\ \rho_{OO}}{R_v}}$$

$$Z_{PUVO} = A + B\,(P_{OO})$$

$$A = -1597$$

$$B = 2.3818$$

$$\text{if } P_{OO} \geq 1010$$

$$\text{set } P_{OO} = 1010$$

$$\ell n\, R_v = A + B\,(\theta_{PUVO}) + C(\theta_{PUVO})^3 + D\,(e)^{\frac{\theta_{PUVO}}{7}} + E\,\theta_{PUVO}\,(e)^{\frac{\theta_{PUVO}}{7}} + F\left[(e)^{\frac{\theta_{PUVO}}{7}}\right]^2$$

$$A = 5.566 \times 10^{-1}$$
$$B = 1.500 \times 10^{-2}$$
$$C = 7.941 \times 10^{-6}$$
$$D = 1.234$$
$$E = -7.255 \times 10^{-2}$$
$$F = 5.069 \times 10^{-2}$$

Fuel, Efficiency

$$\eta_{TF} = \frac{B_{TF}}{B_{ITF}}$$

$$B_{ITF} = K_{10}\ \Delta h_F\ W_T$$

$$\Delta h_F = h_{TIF} - h_{TEF}$$

$$B_{TF} = B_{PF} = K_5 \left(\frac{W_{PF}\ H_F}{\eta_F}\right)$$

$$W_{PF} = W_{FM}$$

$$K_{10} = 1.415$$

$$K_5 = 0.001818$$

Oxidizer, Developed Horsepower

$$B_{TO} = B_{PO}$$

$$B_{PO} = K_5 \left(\frac{W_{PO}\ H_O}{\eta_O}\right)$$

$$K_5 = 0.001818$$

Fuel, Developed Horsepower

$$B_{TF} = B_{PF}$$

$$B_{PF} = K_5 \left(\frac{W_{PF}\ H_F}{\eta_F}\right)$$

$$W_{PF} = W_{FM}$$

Fuel, Weight Flow

$$W_{TF} = W_T$$

$$W_{TO} = W_T - W_B$$

$$W_B = \left[\frac{2K_7\ \gamma_{H2}}{\gamma_{H2} - 1}\ (P_{RNC})^{\frac{2}{\gamma_{H2}}}\right]^{1/2} \left[1 - (P_{RNC})^{\frac{\gamma_{H2}-1}{\gamma_{H2}}}\right]^{1/2} \frac{A_{NB}\ P_{BNI}}{(R_{H2}\ T_{BIR})^{1/2}}$$

$$P_{RNC} = f\ (\beta_{NB}, \gamma_{H2})$$

$$\beta_{NB} = D_{NB}/D_B$$

$$\gamma_{H2},\ M_{H2} = f(T_{H2R}, r_G)$$

$$A_{NB} = K_{13}\,(D_{NB})^2$$

$$K_{13} = 0.7854$$

$$T_{BIR} = T_{TIO} + 460$$

$$P_{BNI} = P_{TEFS}$$

$$P_{TEFS} = \text{Iteration of } P_{TEF}$$

$$P_{TEF} = P_{TEFS}\left[1 + K_8\left(\frac{W_T}{P_{TEFS}}\right)^2 \frac{T_{H2R}}{D^4{}_{TEF}\,M_{H2}}\left(\frac{\gamma_{H2}-1}{\gamma_{H2}}\right)\right]^{\frac{\gamma_{H2}}{\gamma_{H2}-1}}$$

$$K_8 = 38.90$$

GAS GENERATOR

Mixture Ratio

$$r_G = D_1\,(T_{H1})^3 + C_1\,(T_{H1})^2 + B_1\,(T_{H1}) + A_1$$

$$A_1 = 0.2575$$

$$B_1 = 5.586 \times 10^{-4}$$

$$C_1 = -5.332 \times 10^{-9}$$

$$D_1 = 1.1312 \times 10^{-11}$$

$$T_{H1} = T_{TIFM}$$

Flows

$$TC^*{}_{TIF} = D_2\,(T_{H1})^3 + C_2\,(T_{H1})^2 + B_2\,(T_{H1}) + A_2$$

$$A_2 = 4.4226 \times 10^3$$

$$B_2 = 3.2267$$

$$C_2 = -1.3790 \times 10^{-3}$$

$$D_2 = 2.6212 \times 10^{-7}$$

$$P_{TIF} = P_{TIFS}\left[1 + K_8\left(\frac{W_T}{P_{TIFS}}\right)^2 \frac{T_{H1R}}{D^4{}_{TIF}\,M_{H1}}\ \frac{\gamma_{H1}-1}{\gamma_{H1}}\right]^{\frac{\gamma_{H1}}{\gamma_{H1}-1}}$$

$$K_8 = 38.8983$$

Note: P_{TIF} is determined by iteration.

$$T_{H1R} = T_{TIFM} + 460$$

$$M_{H1},\ \gamma_{H1},\ C_p,\ r_{H1} = f\ (T_{H1R}, r_G)$$

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13. ABSTRACT

Six firings of the Rocketdyne J-2 rocket engine (S/N J-2036-1) were conducted during test period J4-1901-12 on October 8, 1968, in Test Cell J-4 of the Large Rocket Facility. This testing was in support of the J-2 engine application on the Saturn IB vehicle. The primary objective of this test period was to evaluate engine start transients with the engine orificed for an uprated thrust level of 240,000 lb_f at a 5.5 mixture ratio. The engine was orificed for performance significantly in excess of the target level, and in fact for a value which could not be attained without exceeding safe operation limits. However, engine start transients were satisfactory with the propellant utilization valve in the open position. The total accumulated firing duration for the six firings was 63.9 sec.

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performance evaluation						

1. Rocket motors -- J-2
2 " " -- Startup
3 " " -- Ignition
0 " " -- Performance

16-3